ÉCOLE DE PHYSIQUE DES HOUCHES

Chimera in the Alps

February 22nd-27th, 2026

UGA
Université Grenoble Alpes

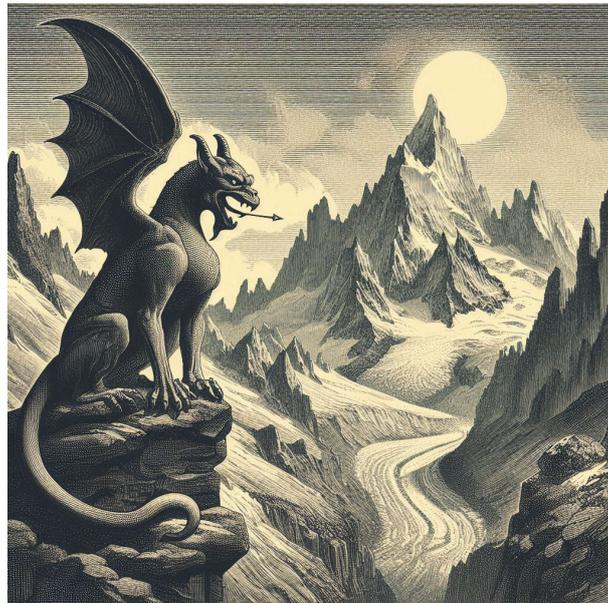CEA GRENOBLE

CNRS
www.cnrs.fr

Grenoble INP

© Guide Vallot

ii

Chimera in the Alps

École de Physique des Houches, Chamonix, France

Feb 22nd - 27th 2026

Contents

Scientific committee

- Olivier Arcizet (Institut Néel, FR)

- Isabella Boventer (Laboratoire Albert Fert, FR)

- Olivier Klein (SPINTEC, FR)

- Silvia Viola Kusminskiy (RWTH Aachen, DE)

- Shuichi Murakami (University of Tokyo, JP)

- Benjamin Pigeau (Institut Néel, FR)

- Georg Schmidt (Universität Halle, DE)

- Takeshi Seki (Tohoku University, JP)

Organizing committee

- Olivier ARCIZET,
  Institut Néel,
  Université Grenoble Alpes, CNRS, Grenoble INP, Grenoble, France

- Olivier KLEIN,
  SPINTEC,
  Université Grenoble Alpes, CEA, CNRS, Grenoble INP, Grenoble, France

- Benjamin PIGEAU,
  Institut Néel,
  Université Grenoble Alpes, CNRS, Grenoble INP, Grenoble, France

In memory of K. Y. Guslienko (1959–2025)

We dedicate this workshop, "Chimera in the Alps," to the memory of Konstantin Yu. Guslienko, an outstanding theorist in the field of magnetism and spin dynamics, who has left a lasting mark on our community.

Throughout a distinguished international career spanning Ukraine, Europe, Asia, and the United States, he combined deep physical insight with the development of analytical models of spin dynamics in spatially textured magnetic ground states and their coupling to other excitations, a topic at the very heart of this workshop. He will also be remembered for his generosity of spirit, inspiring colleagues and collaborators alike.

Beyond his scientific achievements, Konstantin will be cherished for his kindness, curiosity, and unwavering dedication to advancing knowledge. His legacy continues to guide and inspire us.

Sponsors
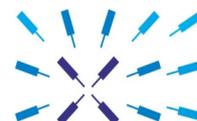
Sponsors of «Chimera in the Alps»

Group picture

Welcome Address

Welcome to the workshop "Chimera in the Alps."

This meeting is dedicated to exploring co-localization and strong coupling among elementary wave excitations in condensed matter systems—spins, magnons, phonons, and photons. By examining the shared dynamics of these hybrid excitations, we aim to deepen our understanding of their fundamental interactions and to uncover their potential for next-generation information technologies. The program highlights recent advances, open challenges, and future directions in the field, with particular attention to pathways toward scalable and integrable devices.

The workshop brings together 37 invited oral presentations and 24 poster contributions, along with four tutorial lectures intended to provide a common foundation and encourage cross-disciplinary dialogue. Generous time has been set aside for discussion, reflection, and informal exchange, all within the inspiring setting of the French Alps.

We look forward to a week of lively scientific interaction and hope you find the experience both stimulating and rewarding.

On behalf of the Organizing Committee

Olivier Arcizet, Olivier Klein, and Benjamin Pigeau

Introduction

Les Houches School of Physics has been welcoming physicists from around the world since 1951. The School has seen the biggest names in modern physics training young researchers at the start of their careers, some of whom have since won Nobel prizes for physics. The school perpetuates a tradition of excellence, while continuing to adapt to the evolutions of science.

History

The École de Physique des Houches was founded in 1951 by Cécile DeWitt-Morette in the aftermath of the Second World War. At that time, the teaching and practice of modern physics in France had fallen behind international developments. The School was created to help rebuild scientific excellence by bringing leading international physicists to teach small groups of advanced students and young researchers in an intensive format.

The dynamic and visionary Cécile DeWitt-Morette succeeded in building a school, with the few resources available, to which leading world specialists would come to share their knowledge with groups of around thirty students from different countries (mostly France and other European countries, but not only). The setting is idyllic, lying above the Chamonix valley, in full view of the Mont-Blanc mountains. However, back then, living conditions were very rudimentary: the sessions lasted eight weeks (the two months of the university summer holidays), staying in mountain chalets will no facilities, a few kilometres from Les Houches village.

From its inception, the School combined extended lecture courses with close interaction between lecturers and participants. Over the decades, it has welcomed many prominent figures in modern physics and has trained generations of young scientists, several of whom later made major contributions to the field.

Today, the École de Physique des Houches continues to serve as an international center for advanced scientific training and research exchange. It hosts three main types of activities: long-format Summer School sessions for advanced graduate students and postdoctoral researchers; specialized workshops bringing together theorists and experimentalists; and a Predoctoral School aimed at broadening the scientific foundations of early-stage doctoral students. Through these programs, the School maintains its original mission of fostering high-level scientific education and collaboration in physics.

Events

The School hosts three main types of events.

The Summer School sessions are intended for advanced graduate students and young postdoctoral researchers. Lasting four to five weeks, they offer extended lecture courses that provide in-depth coverage of a subject up to the frontiers of current research, while encouraging sustained interaction and collaboration among participants. Programs are selected by the Board approximately two years in advance.

Workshops are organized throughout the rest of the year and last from one to three weeks. They bring together theoreticians and experimentalists to exchange ideas and explore new research directions, with significant time devoted to discussion in small working groups.

The Predoctoral School is designed for early-stage doctoral students. Its objective is to broaden their foundation in physics, place their thesis work in a wider context, and help prevent premature over-specialization.

Access

By plane

Geneva Airport is 1 hour drive from les Houches. Once you have landed, you can reach the school using a shuttle service, the regular bus service or by train.

Shuttle service

The simplest way is to use a shuttle service (approximately 40 euros up to the school, book at least three days in advance). If you already have your return date, we would recommend to book a return trip. > Consult the list of companies

Beware: we do not recommend the Alpybus company (they do not reach the school).

Price discounts are available with Mountain Drop-Offs. To find Mountain Drop-Offs' meeting point easily in the Geneva Airport please consult the video How to find Mountain Drop-Offs at Geneva Airport.

Regular bus service

There is also a regular bus service between Geneva and Les Houches (only once or twice a day). One should then take a taxi for the last 5 kms from the Les Houches village to the school (the total cost is similar to that of the limousine).

Train

One can also travel from Geneva to Les Houches by train (+ taxi from the train station to the School), but it is quite complicated (3 connections) and long (go through Annemasse on the French side or through Martigny on the Swiss side).

By train

Arrival at the Les Houches station, with one change at Saint-Gervais (from France), or at Martigny (from Switzerland). There are about 10 trains per day between St Gervais and Les Houches (schedules, 20mn trip). Then we strongly advise you to take a taxi to go up to the school (5km).

Taxi phone numbers :

- (+33/0)6-07-26-36-62,

- (+33/0)6.22.75.19.37,

- (+33/ 0)6.12.35.30.72.

By road

Les Houches are easily accessible from France (A41 highway), from Switzerland (Martigny and Col des Montets) and from Italy through the Mont Blanc Tunnel. From Geneva and Le Fayet

8km before Chamonix, 300 m after passing under the tunnel, bear right by the first road out for "Les Houches Bellevue". When arriving at the cable car station "Bellevue", turn right and continue upwards (roughly 2 km starting from the teleferic). 500m after the cable car station "Prarion", turn left and follow small arrows at crossroads. Continue up to the end of Route de la Côte des Chavants. Here you are!

From Chamonix

Bear right for "Les Houches-Chef-Lieu", turn right in Les Houches, go ahead at the cable car station "Bellevue". Then proceed as above.

Cars may be rented from Geneva and from Chamonix, it is useful to make a reservation. What to do in Les Houches and in the valley?

See for example: `http://www.leshouches.com` and `http://www.chamonix.com`

ADDRESS OF THE SCHOOL:

Les Houches School of Physics
140 Chemin de la Côte
F-74310 Les Houches
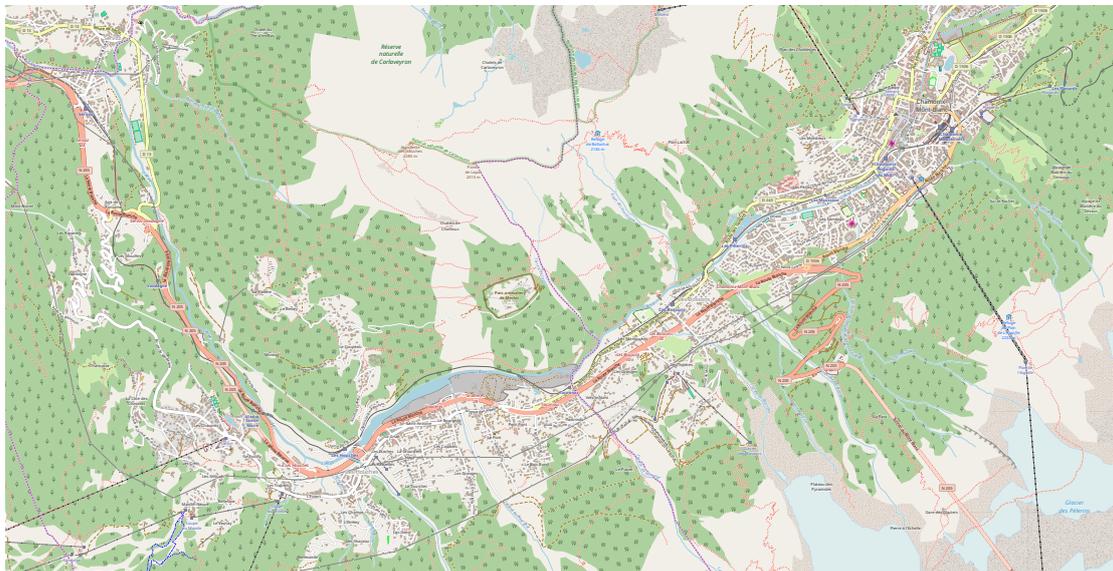
Maps

Open street maps
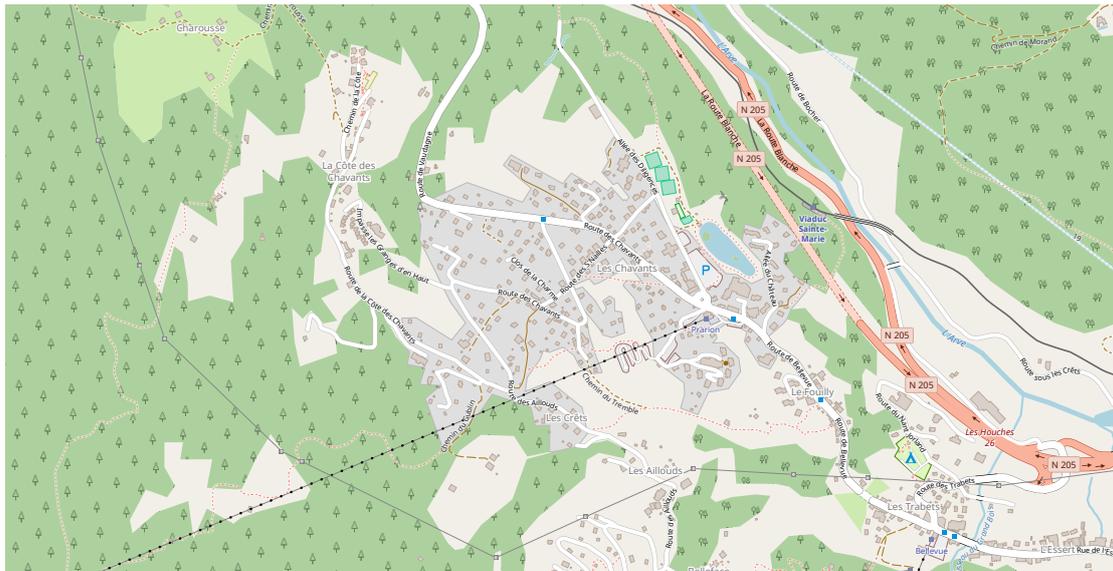

Figure 1: Village de Chamonix

Figure 2: Hameaux des Houches

Map of the École de Physique

Practical information

The school property is at your disposal for the session; please respect it and if possible improve it.
The last person leaving any room or building should turn the lights off.
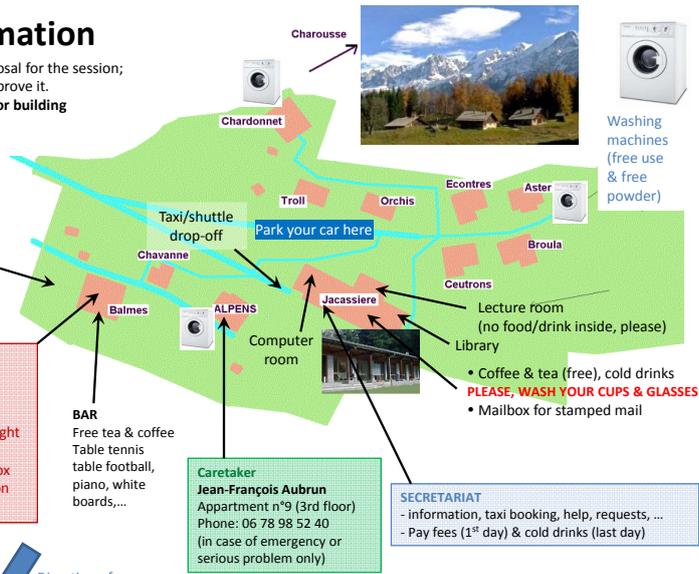
Charousse

Chardonnet

Washing machines (free use & free powder)

Econtres

Troll   Orchis   Aster

"Garden"
Our neighbors thank you for keeping this place not too noisy

Taxi/shuttle drop-off

Park your car here

Broula

Chavanne

Ceutrons

Balmes   ALPENS

Lecture room (no food/drink inside, please)

Jacassiere

Library

RESTAURANT
Breakfast: 7.45 – 8.45 am
lunch: 12.30 pm
dinner : 7.30 pm
• Drinks (not included) can be bought on individual basis
• Participants who wish a picnic box instead of a meal should register on the list 24 h in advance.

Computer room

• Coffee & tea (free), cold drinks
PLEASE, WASH YOUR CUPS & GLASSES
• Mailbox for stamped mail

BAR
Free tea & coffee
Table tennis table football, piano, white boards,…

Caretaker
Jean-François Aubrun
Appartment n°9 (3rd floor)
Phone: 06 78 98 52 40
(in case of emergency or serious problem only)

SECRETARIAT
- information, taxi booking, help, requests, …
- Pay fees (1st day) & cold drinks (last day)

Direction of Mont-Blanc

Mountain activities are at your own risk
Before any hike or climb, please put a note in the special book provided and include the names of the participants, approximate itinerary and schedule. We draw your attention to the fact we only hold a collective insurance for accidents occurring on the school campus.

Ski slopes: Prarion – Saint-Gervais

Program

Timetable of the "Chimera in the Alps" workshop, 2026

Time	Sunday, Feb 22	Monday, Feb 23	Tuesday, Feb 24	Wednesday, Feb 25	Thursday, Feb 26	Friday, Feb 27
07:00 - 08:00		07:30 Breakfast	07:30 Breakfast	07:30 Breakfast	07:30 Breakfast	07:30 Breakfast
08:00 - 09:00		08:15 Welcome / 08:30 Caroline Ross T01	08:30 Maria-Jose Martinez Perez T02	08:30 John Davis T03	08:30 Victor Bittencourt T04	08:30 Madjid Anane I32 / 09:05 Ping Che I33
09:00 - 10:00		09:40 William Legrand I01	09:40 Grégoire De Loubens I08	09:40 Katrin Schultheiss I15	09:40 Gerrit Bauer I25	09:40 Yoichi Nii I34
10:00 - 11:00		10:15 Coffee break / 10:45 Andrii Chumak I02	10:15 Coffee break / 10:45 Satoshi Tomita I09	10:15 Coffee break / 10:45 Gabriel Hetet I16	10:15 Coffee break / 10:45 Yaroslav Blanter I26	10:15 Coffee break / 10:45 Debarghya Dutta I35
11:00 - 12:00		11:20 Hans Huebl I03 / 11:55 Babu Nandan I04	11:20 Yukio Nozaki I10 / 11:55 Seth Kurfman I11	11:20 Aristide Lemaître I17 / 11:55 Christina Psaroudaki I18	11:20 Thierry Valet I27 / 11:55 Akashdeep Kamra I28	11:20 Martijn Dols I36 / 11:55 Davit Petrosyan I37
12:00 - 13:00		12:30 Lunch	12:30 Lunch	12:30 Lunch	12:30 Lunch	12:30 Lunch
13:00 - 14:00		13:30 Informal discussions	13:30 Informal discussions	13:30 Informal discussions	13:30 Informal discussions	
14:00 - 15:00						
15:00 - 16:00						
16:00 - 17:00	16:00 Registration					
17:00 - 18:00		17:00 Triubute / 17:15 Teruo Ono I05	17:15 Albrecht Jander I12	17:15 James O'Sullivan I19	17:15 Matthias Althammer I29	
18:00 - 19:00		17:50 Yi Li I06 / 18:25 Katharina Lasinger I07	17:50 Carlos Gonzalez I13 / 18:25 Daiki Hatanaka I14	17:50 Hiroki Arisawa I20 / 18:25 Takashi Kikkawa I21	17:50 Masamitsu Hayashi I30 / 18:25 Richard Schlitz I31	
19:00 - 20:00	19:00 Cocktail / 19:30 Dinner	19:00 Poster pitch / 19:30 Dinner	19:30 Dinner	19:00 Dinner	19:30 Banquet	
20:00 - 21:00		20:30 Poster 1	20:30 Poster 2	20:00 Christian Degen I22 / 20:35 Toeno Van Der Sar I23		
21:00 - 22:00				21:10 Aurore Finco I24		

Sunday, February 22ND 2026

16:00 - 19:30   *Registration*

19:00 - 19:30   *Welcome cocktail*

Monday, February 23RD 2026

07:30 - 08:30   *Breakfast*

08:15 - 08:30   *Welcome Address*

Session: Tutorials

08:30 - 09:40   *T01 : Invited Talk.*

Tutorial: How to Make Complex Oxide Films and Heterostructures for Spintronics.

Caroline Ross
Massachusetts Institute of Technology (United States)

Session: Material growth and nanolithography

09:40 - 10:15   *I01 : Invited Talk.*

Composition-Tuneable Substituted Iron Garnets for Hybrid Magnetic Excitations.

William Legrand
CNRS

10:15 - 10:45   *Coffee break*

10:45 - 11:20   *I02 : Invited Talk.*

Spin-Wave Transport at Cryogenic Temperatures.

Andrii Chumak
University of Vienna (Austria)

11:20 - 11:55	*I03 : Invited Talk.*

Multi-Mode Coupling in Magnon-Phonon Hybrids.

Hans Huebl
Walther-Meißner-Institute (Germany)

11:55 - 12:30	*I04 : Invited Talk.*

Fabrication and Integration of Suspended YIG Micro Disk on Microwave Antennas.

Babu Nandan
ICN2 - Institut Catala De Nanociencia I Nanotecnologia (Spain)

12:30 - 13:30	*Lunch*
13:30 - 17:00	*Informal discussions*
17:00 - 17:15	*Tribute to K. Guslienko*

Session: Cavity magnonics 1

17:15 - 17:50	*I05 : Invited Talk.*

Superconducting Diode Effect.

Teruo Ono
Institute for Chemical Research

17:50 - 18:25	*I06 : Invited Talk.*

Coherent Control of Magnons.

Yi Li
Argonne National Laboratory [Lemont] (United States)

18:25 - 19:00	*I07 : Invited Talk.*

Hybrid Magnon–Phonon Phenomena in Magnetic-Insulator/Piezoelectric Heterostructures.

Katharina Lasinger
Department of Physics

19:00 - 19:30   *Poster pitch*

19:30 - 20:30   *Dinner*

20:30 - 22:00   *Poster 1*

07:30 - 08:30   *Breakfast*

Session: Tutorials

08:30 - 09:40   *T02 : Invited Talk.*

Magnon-Photon Coupling in Realistic Experiments.

Maria-Jose Martinez Perez
Instituto De Nanociencia Y Materiales De Aragón (Spain)

09:40 - 10:15   *I08 : Invited Talk.*

Weak Coupling between Spin-Wave and Mechanical Modes of Suspended YIG Microdisks.

Grégoire De Loubens
Service De Physique De L'état Condensé (France)

10:15 - 10:45   *Coffee break*

10:45 - 11:20   *I09 : Invited Talk.*

Synthetic Motion of Magnon-Polaritons in Metamaterials.

Satoshi Tomita
Tohoku University (Japan)

11:20 - 11:55   *I10 : Invited Talk.*

Acoustic-Mechanical Hybrid Resonance for Enhanced Magnon-Phonon Coupling.

Yukio Nozaki
Department of Physics

11:55 - 12:30   *I11 : Invited Talk.*

TBD.

Seth Kurfman
Institut Für Physik Martin-Luther-Universität Halle Wittenberg - Martin-Luther-University Halle Wittenberg (Germany)

12:30 - 13:30   *Lunch*

13:30 - 17:15   *Informal discussions*

Session: Magneto-acoustic

17:15 - 17:50   *I12 : Invited Talk.*

Phonon Parametric Pumping for Magnonics.

Albrecht Jander
School of Electrical Engineering and Computer Science [Oregon State University] (United States)

17:50 - 18:25   *I13 : Invited Talk.*

Phonon-Assisted Generation of Propagating Quantum Magnonic States.

Carlos Gonzalez
Vienna University of Technology = Technische Universität Wien (Austria)

18:25 - 19:00   *I14 : Invited Talk.*

Generation of Magnon Polaron in Strongly Coupled Cavity Magnomechanical System.

Daiki Hatanaka
Basic Research Laboratories

19:30 - 20:30   *Dinner*

20:30 - 22:00   *Poster 2*

07:30 - 08:30   *Breakfast*

Session: Tutorials

08:30 - 09:40   *T03 : Invited Talk.*

Cavity Magnomechanics as a Hybrid Magnonic System.

John Davis
University of Alberta (Canada)

Session: Cavity magnonics 3

09:40 - 10:15   *I15 : Invited Talk.*

Self-Induced Floquet Magnons in Magnetic Vortices.

Katrin Schultheiss
Helmholtz-Zentrum Dresden-Rossendorf (Germany)

10:15 - 10:45   *Coffee break*

10:45 - 11:20   *I16 : Invited Talk.*

Spin-Mechanics with Ensembles of NV Centers in Diamond.

Gabriel Hetet
Laboratoire De Physique De L'ENS - ENS Paris (France)

11:20 - 11:55   *I17 : Invited Talk.*

.

Aristide Lemaître

11:55 - 12:30   *I18 : Invited Talk.*

Magnon Superlattices around Skyrmions in Frustated Magnets.

Christina Psaroudaki
Laboratoire De Physique De L'ENS - ENS Paris (France)

12:30 - 13:30   *Lunch*

Session: Nuclear Magnetic Resonance

17:15 - 17:50   *I19 : Invited Talk.*

Control and Readout of Single Nuclear Spins via Microwave Photon Counting.

James O'Sullivan
Service De Physique De L´tat Condensé (SPEC - UMR3680 CEA-CNRS(Ex-URA 2464)

17:50 - 18:25   *I20 : Invited Talk.*

Coupling of Electron-Spin and Nuclear-Spin Excitations.

Hiroki Arisawa
Department of Applied Physics

18:25 - 19:00   *I21 : Invited Talk.*

Electric Manipulation of Coupled Nuclear- and Electron-Spin Dynamics.

Takashi Kikkawa
Japan Atomic Energy Agency (Japan)

19:00 - 20:00   *Dinner*

Session: NV-center magnetometry

20:00 - 20:35   *I22 : Invited Talk.*

Imaging the Mechanics of Domain Wall Motion with a Single Spin Quantum Magnetometer.

Christian Degen
Department of Physics

20:35 - 21:10   *I23 : Invited Talk.*

Magnetic Imaging of Spin Waves and Supercurrents Using Spins in Diamond.

Toeno Van Der Sar
Delft University of Technology (Netherlands)

21:10 - 21:45   *I24 : Invited Talk.*

Spin Waves Confined in Microstructures Investigated with a Scanning NV Center Microscope.

Aurore Finco
Laboratoire Charles Coulomb (France)

07:30 - 08:30   *Breakfast*

Session: Tutorials

08:30 - 09:40   *T04 : Invited Talk.*

Hybrid Magnonics: Recent past and Future Developments.

Victor Bittencourt
Institut De Science Et D'Ingénierie Supramoléculaires (France)

Session: Theory

09:40 - 10:15   *I25 : Invited Talk.*

Chimeras in Ferroelectrics.

Gerrit Bauer
WPI Advanced Institute for Materials Research (Japan)

10:15 - 10:45   *Coffee break*

10:45 - 11:20   *I26 : Invited Talk.*

Quantum Magnonics in Magnon-Qubit Architecture.

Yaroslav Blanter
Kavli Institute of Nanoscience

11:20 - 11:55   *I27 : Invited Talk.*

Spin-Orbit Interaction in Azimuthal Spin Waves.

Thierry Valet
SPINtronique Et TEchnologie Des Composants (France)

11:55 - 12:30   *I28 : Invited Talk.*

Quantum Sensing Magnons Using a Phonon as the Probe.

Akashdeep Kamra
University of Kaiserslautern / Rheinland-Pfälzische Technische Universität Kaiserslautern (Germany)

Session: Magneto-transport

17:15 - 17:50   *I29 : Invited Talk.*

All-Electrical Angular Momentum Transport Experiments between Isolated Ferromagnetic Metal Strips.

Matthias Althammer
Walther-Meißner-Institut

17:50 - 18:25   *I30 : Invited Talk.*

Tunable Complex Magnon-Phonon Coupling in Synthetic Antiferromagnets.

Masamitsu Hayashi
The University of Tokyo (Japan)

18:25 - 19:00   *I31 : Invited Talk.*

Controlling Magnons and Their Transport by Electronic Spin Injection.

Richard Schlitz
Department of Physics [Konstanz] (Germany)

19:30 - 20:30   *Banquet*

07:30 - 08:30   *Breakfast*

Session: Magnonics

08:30 - 09:05   *I32 : Invited Talk.*

Spin-Wave Modes and Nonlinear Interactions in Bi:YIG Disks for Magnonic Neural Network Implementation in Reciprocal Space.

Madjid Anane
Laboratoire Albert Fert (Ex-UMPhy Unité Mixte De Physique CNRS/Thales) (France)

09:05 - 09:40   *I33 : Invited Talk.*

Real-Space Imaging of Magnons Interacting with Noncollinear Magnetic Textures.

Ping Che
Unité Mixte De Physique CNRS/Thales (France)

09:40 - 10:15   *I34 : Invited Talk.*

Topological and Nonreciprocal Phononics in the Gigahertz Regime.

Yoichi Nii
Department of Applied Physics and Physico-Informatics (Japan)

10:15 - 10:45   *Coffee break*

10:45 - 11:20   *I35 : Invited Talk.*

Decoherence Spectroscopy of Spin Waves in Van Der Waals Antiferromagnets.

Debarghya Dutta
Department of Physics and Astronomy [Basel] (Switzerland)

11:20 - 11:55   *I36 : Invited Talk.*

Steady-State Entanglement of Spin Qubits Mediated by Non-Reciprocal and Chiral Magnons.

Martijn Dols
RWTH Aachen University (Germany)

11:55 - 12:30   *I37 : Invited Talk.*

Magnon Kerr Effect in a Ferrimagnetic Thin Film.

Davit Petrosyan
Department of Materials
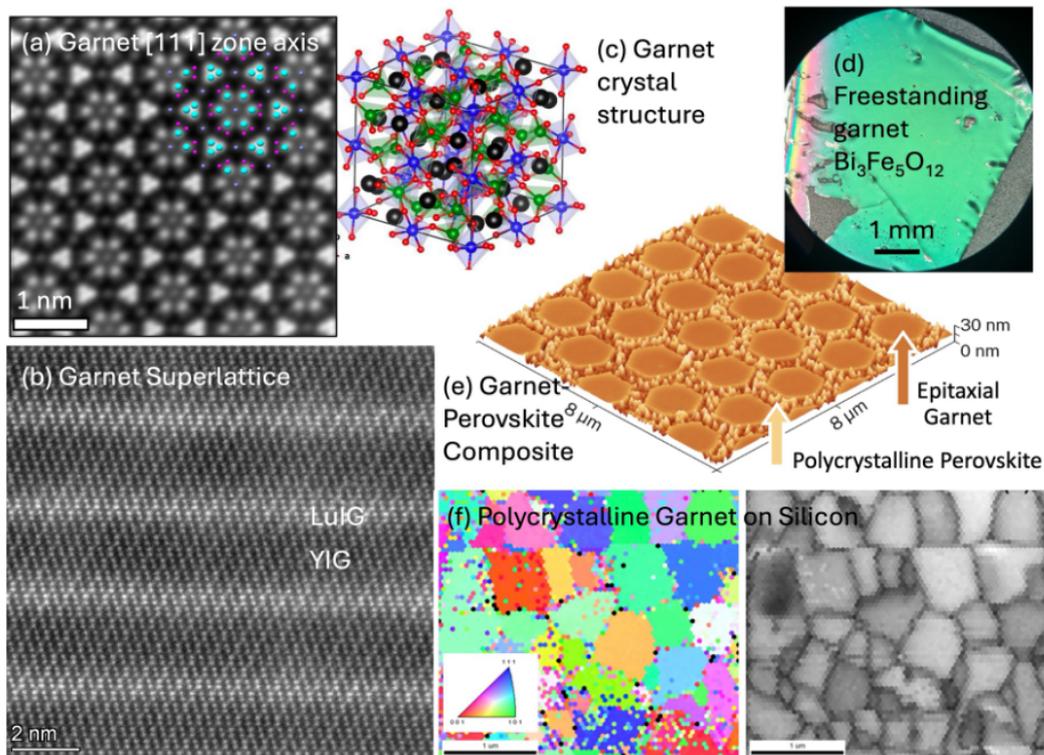
12:30 - 13:30   *Lunch*

Tutorials

How to Make Complex Oxide Films and Heterostructures for Spintronic

Caroline Ross[1,*]

[1]Department of Materials Science and Engineering, MIT, Cambridge, MA 02139 USA

*contact: caross@mit.edu

Complex oxides encompass a vast range of magne4cally ordered materials whose crystal symmetry, magne4za4on, anisotropy, damping, magnetoop4cal response, conduc4vity, and other proper4es can be widely tuned through ca4on site occupancy, strain state, point defects, substrate and interface design. Iron garnets such as YIG, spinels such as cobalt ferrite, perovskite- based materials such as orthoferrites, and hema4te are par4cularly important spintronic materials, and can be grown by a range of processing routes including pulsed laser deposi4on, oxide molecular beam epitaxy, and spuBering. With an emphasis on garnets, I will describe how to grow high quality spintronic oxides and heterostructures, and how their proper4es can be designed and manipulated.

(a) Garnet [111] zone axis
(b) Garnet Superlattice — LuIG, YIG
(c) Garnet crystal structure
(d) Freestanding garnet $Bi_3Fe_5O_{12}$
(e) Garnet-Perovskite Composite — Epitaxial Garnet, Polycrystalline Perovskite
(f) Polycrystalline Garnet on Silicon

Magnon-Photon Coupling in Realistic Experiments

M. J. Martínez-Pérez[1,*]

[1]Instituto De Nanociencia Y Materiales De Aragón, INMA - CSIC, Unizar, Spain

*contact: pemar@unizar.es

There are different theoretical methods that provide good estimations of the magnon-photon coupling strength in saturated ferromagnets, where the homogeneous (Kittel, $k = 0$) or high-k (magnetostatic) modes can be excited. However, this is only true under the assumption that the magnetic susceptibility of the ferromagnet can be calculated. In other words, a precise knowledge of the demagnetizing factors is needed. Unfortunately, the latter can be calculated exactly only for ellipsoids of revolution. In contrast, the ground state of real ferromagnets is largely non homogeneous, e.g., domain walls separating regions with different magnetization direction; curls of the magnetization referred as vortices; and magnetic skyrmions, i.e., topologically protected defects stabilized in materials featuring asymmetric exchange interactions. The dynamic evolution of these objects cannot be calculated analytically and micromagnetic computation is typically needed.

To make things even more complicated, electromagnetic cavities come in a number of ways, starting from the early implementations using Fabry-Perot mirrors, up to solid-state cavity implementations. Experiments on cavity magnonics benefit from the use of (quasi)homogeneous microwave field configurations in three dimensional cavities that only couple to the Kittel mode in magnetic spheres. In contrast, the microwave field distribution can become largely non-homogeneous as in the case of superconducting coplanar cavities or even exhibit parity rules as in the case of re-entrant post cavities.

In this tutorial I will show several ways of calculating the magnon-photon coupling in realistic setups, including the first software[1] capable of self-consistently simulating the dynamics of coupled cavity-ferromagnet systems at the micromagnetic level, including inhomogeneous textures and cavity fields and in any coupling regime. This tools allow the numerical simulation of hybrid magnon-photon polaritons and magnons dynamics involving direct photon coupling or virtual magnon-magnon interactions. [2].

REFERENCES

[1]*Https://github.com/mumax3-cqed/mumax3-cqed*.

[2]S. M.-L. del Rincón, J. Román-Roche, A. Martín-Megino, D. Zueco, and M. J. Martínez-Pérez, *Mumax3-cqed: an extension of mumax3 to simulate magnon-photon interactions in cavity qed*, 10.48550/ARXIV.2410.00966 (2024).

Cavity Magnomechanics as a Hybrid Magnonic System

John P. Davis[1,*], **Yunhu Huang**[1], **Mehri Ebrahimi**[1]

[1]Department of Physics, University of Alberta, Edmonton, Alberta T6G 2E9, Canada

*contact: jdavis@ualberta.ca

Hybrid quantum systems based on magnons provide a versatile platform for studying coherent interactions among microwave photons, phonons, and collective spin excitations. A key advantage of magnons is their strong tunability via an external bias magnetic field, which enables controlled coupling to multiple degrees of freedom. Strong magnetic-dipole interaction between microwave photons and magnons places the system deep in the strong coupling regime, giving rise to hybrid cavity–magnon polariton modes [1]. In addition, magnons weakly couple to mechanical motion through the magnetostrictive interaction, forming the basis of cavity magnomechanics [2, 3].

In cavity magnomechanics, the microwave cavity mode is strongly hybridized with the magnon mode, while the magnon simultaneously interacts with mechanical vibrations in the weak magnomechanical coupling regime, as schematically illustrated in Fig. 1. A prominent feature of this platform is the triple-resonance condition, in which the phonon frequency matches the frequency splitting between the hybrid cavity–magnon polariton modes, enabling selective cavity enhancement of scattering processes. This selective enhancement provides access to a range of magnomechanical phenomena, including dynamical backaction, mechanical amplification and cooling, phonon lasing, and the generation of quantum correlations [3].
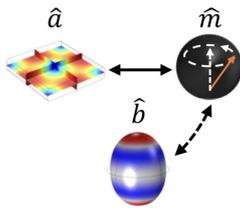

Figure 1: Schematic of the coupled magnomechanical system. $\hat{a}$ denotes the microwave cavity mode, $\hat{m}$ a magnon mode in the spherical ferromagnetic sample, and $\hat{b}$ a mechanical mode. Solid and dashed lines indicate linear magnon–photon and parametric magnon–phonon couplings, respectively.

Using this framework, our experiments directly observe the fundamental signatures of magnon-induced dynamical backaction on a mechanical mode, establishing cavity magnomechanics as an experimentally accessible analogue of cavity optomechanics [3]. Beyond backaction physics, our group has developed a theoretical proposal for quantum correlation–based thermometry in cavity magnomechanics [4], in which cross-correlation measurements are used to distinguish thermomechanical motion from magnon-induced backaction. Most recently, we have extended cavity magnomechanics into the cryogenic regime down to $\sim 9\,\mathrm{K}$ [5], providing an essential step toward quantum-enabled sensing and thermometry in low-temperature hybrid quantum systems.

Overall, the strong and tunable photon–magnon hybridization, together with magnetostrictive coupling to mechanical motion, endows hybrid magnetic systems with promising advantages for quantum technologies.

REFERENCES

[1]X. Zhang, C.-L. Zou, L. Jiang, and H. X. Tang, *Strongly coupled magnons and cavity microwave photons*, Physical Review Letters **113**, 10.1103/physrevlett.113.156401 (2014).

[2]X. Zhang, C.-L. Zou, L. Jiang, and H. X. Tang, *Cavity magnomechanics*, Science Advances **2**, 10.1126/sciadv.1501286 (2016).

[3]C. A. Potts, E. Varga, V. A. S. V. Bittencourt, S. V. Kusminskiy, and J. P. Davis, *Dynamical backaction magnomechanics*, Physical Review X **11**, 10.1103/physrevx.11.031053 (2021).

[4]C. Potts, V. Bittencourt, S. V. Kusminskiy, and J. Davis, *Magnon-phonon quantum correlation thermometry*, Physical Review Applied **13**, 10.1103/physrevapplied.13.064001 (2020).

[5]Y. Huang, P. M. C. Rourke, A. Peruzzi, et al., *Cryogenic magnomechanics for thermometry applications*, Applied Physics Letters **127**, 10.1063/5.0271756 (2025).

Hybrid Magnonics: Recent past and Future Prospects

V. A. S. V. Bittencourt[1,*]

[1]Institut De Science Et D'Ingénierie Supramoléculaires (ISIS, UMR7006), Université De Strasbourg, 67000 Strasbourg, France
*contact: sant@unistra.fr

Quantum technologies requires multiple functionalities that can only be achieved by different physical systems in hybrid architectures. In such a context, spin-waves and their quanta, called magnons, are prospect components in hybrid systems for added functionality and integration with different degrees-of-freedom. Magnons can couple to different excitations, such as optical and microwave photons, elastic phonons, and to solid-state and superconducting qubits. Magnons exhibit features, such as tunable frequency and nonlinear behavior, that can be exploited in applications, such as sensing and quantum state generation. In this keynote lecture, I will present an overview of different hybrid magnonic systems, including their theoretical description, applications and future prospects. The lecture will briefly cover different aspects of cavity optomagnonics, including applications for magnon state generation [1] and tomography [2], as well as an epsilon-near-zero based architecture in which strong magnon-photon coupling could be achieved. I will also review systems coupling NV-centers and magnons, with applications for generation of steady-state entangled spin states [3] and for probing spin transport in magnetic materials, in particular in altermagnets [4].

REFERENCES

[1]V. A. S. V. Bittencourt, V. Feulner, and S. V. Kusminskiy, *Magnon heralding in cavity optomagnonics*, Phys. Rev. A **100**, 013810 (2019).

[2]S. Sharma, S. Viola Kusminskiy, and V. A. S. V. Bittencourt, *Quantum tomography of magnons using brillouin light scattering*, Phys. Rev. B **110**, 014416 (2024).

[3]M. Dols, M. Cherkasskii, V. A. S. V. Bittencourt, et al., *Steady-state entanglement of spin qubits mediated by non-reciprocal and chiral magnons*, arXiv preprint arXiv:2509.13094 (2025).

[4]V. A. S. V. Bittencourt, H. Hosseinabadi, J. Sinova, L. Šmejkal, and J. Marino, *Quantum-impurity sensing of altermagnetic order*, arXiv preprint arXiv:2508.04788 (2025).

Talks

Composition-Tuneable Substituted Iron Garnets for Hybrid Magnetic Excitations

William Legrand[1,*]

[1]Université Grenoble Alpes, CNRS, Institut Néel, Grenoble, France

*contact: william.legrand@neel.cnrs.fr

Iron garnets are outstanding low-temperature hosts for hybrid condensed matter excitations, offering low dissipation of magnons and phonons, high spin density, and robust magneto-elastic and magneto-optical couplings. Magnons in iron garnets can therefore interact coherently with microwaves, phonons, and optical photons, key to enabling quantum transduction and ultra-sensitive detection. While the most established implementations of these concepts rely on bulk magnets [1–3], on-chip equivalents promise superior functionality, coherence, and scalability. For integrated hybrid systems to attain the quantum regime, the efficient couplings in iron garnets are nonetheless a double-edged sword. The same properties that facilitate strong coupling between distinct quasi-particles also reinforce decay to the environment, compromising coherence. As recognised in other research fields, a multi-faceted engineering of the material is inescapable if one wants to harness couplings while avoiding dissipation. This is likely the most critical requirement for fundamental investigations of quantum coherence in low-spin-number systems, or for building cryogenic hybrid magnonic devices useful to quantum engineering.

In this talk, I will present our recent progress on cation substitutions in iron garnets to tackle this challenge. Added yttrium in off-stoichiometric yttrium iron garnet (YIG) enables lattice parameter tuning and matching with yttrium scandium gallium garnet (YSGG), a commercial substrate free of paramagnetic species. We will show that such Y-rich YIG [4] can be grown by a convenient physical vapour co-deposition approach, maintaining excellent structural properties and magnetization dynamics [5]. The change of substrate fulfils a first requirement for integrated quantum magnonics, as it reduces dissipation in thin and ultrathin films at helium temperatures [5–8]. We will also report on unsubstituted YIG films grown on YSGG by liquid phase epitaxy (LPE): this route presently achieves lower dissipation at low temperatures, despite strain [8]. Alternatively, ultrathin layers of Bi-substituted YIG can be grown with excellent quality down to 2–3 nm in thickness [9], forming another excellent platform for hybrid magnonics [10]. This talk will conclude with a few insights on how to bridge the gap between the structural advantages brought by LPE and the compositional flexibility of physical vapour deposition.

REFERENCES

[1]D. Lachance-Quirion, Y. Tabuchi, A. Gloppe, K. Usami, and Y. Nakamura, *Hybrid quantum systems based on magnonics*, Appl. Phys. Express **12**, 070101 (2019).

[2]D. D. Awschalom, C. R. Du, R. He, et al., *Quantum Engineering With Hybrid Magnonic Systems and Materials (Invited Paper)*, IEEE Trans. Quantum Eng. **2**, 5500836 (2021).

[3]H. Y. Yuan, Y. Cao, A. Kamra, R. A. Duine, and P. Yan, *Quantum magnonics: When magnon spintronics meets quantum information science*, Phys. Rep. **965**, 1–74 (2022).

[4]T. Su, S. Ning, E. Cho, and C. A. Ross, *Magnetism and site occupancy in epitaxial Y-rich yttrium iron garnet films*, Phys. Rev. Mater. **5**, 094403 (2021).

[5]W. Legrand, Y. Kemna, S. Schären, et al., *Lattice-Tunable Substituted Iron Garnets for Low-Temperature Magnonics*, Adv. Funct. Mater., 2503644 (2025).

[6]S. Guo, D. Russell, J. Lanier, et al., *Strong on-Chip Microwave Photon–Magnon Coupling Using Ultralow-Damping Epitaxial $Y_3Fe_5O_{12}$ Films at 2 K*, Nano Lett. **23**, 5055–5060 (2023).

[7]R. O. Serha, C. Dubs, C. Guguschev, et al., *YSGAG: The Ideal Substrate for YIG in Quantum Magnonics*, arXiv, 2508.19044 (2025).

[8]J. Ben Youssef, N. Beaulieu, R. Schlitz, et al., *Low-temperature-compatible iron garnet films grown by liquid phase epitaxy*, arXiv, 2509.06242 (2025).

[9]H. Wang, W. Legrand, D. Petrosyan, et al., *Ultrathin bismuth-yttrium iron garnet films with tunable and compensated magnetic anisotropy*, arXiv, 2510.07465 (2025).

[10]H. Wang, W. Legrand, R. Schlitz, and P. Gambardella, *Current-Controlled Magnon–Magnon Coupling in an On-Chip Cavity Resonator*, Nano Lett. **25**, 9090–9097 (2025).

Spin-Wave Transport at Cryogenic Temperatures

Andrii Chumak[1,*]

[1]Faculty of Physics, University of Vienna, Vienna, Austria

*contact: andrii.chumak@univie.ac.at

Quantum magnonics, a field that harnesses magnons (spin-wave quanta) for quantum technologies, holds great promise for the realisation of solid-state quantum technologies at the nanoscale. Yttrium iron garnet (YIG) is the material of choice due to its low magnon damping [1]. While ferromagnetic resonance (FMR) magnons have already been used for quantum magnonics studies [2, 3], the transition from standing to propagating magnons is crucial for realising devices with spatially separated magnon sources and detectors [4]. Achieving this requires YIG films, usually grown on paramagnetic gadolinium gallium garnet (GGG) substrates.

In a series of experimental studies of magnon transport in YIG/GGG systems at temperatures down to tens of mK [5–7], we reveal a significant role of a stray field effect formed by the partially magnetised paramagnetic GGG substrate. This stray field opposes the applied biasing field, shifting the FMR frequency to lower frequencies [5], and could reach up to 40 mT in our studies. Subsequent investigations of the FMR linewidth revealed an approximately tenfold increase in the Gilbert damping in YIG films on GGG with decreasing temperature. We show that the dominant mechanism responsible for the FMR broadening is the non-uniform GGG stray field [6]. To understand the losses of propagating magnons in YIG/GGG, we have performed propagating spin wave spectroscopy (PSWS) measurements for temperatures between 4 K and 26 mK [7]. We show an increase in the dissipation rate with wavenumber at cryogenic temperatures, caused by dipolar coupling of the YIG film to the partially magnetised GGG substrate.

Yttrium scandium gallium aluminum garnet (YSGAG) substrate has recently been presented as a diamagnetic alternative to GGG [8]. We demonstrated that the YIG/YSGAG system maintains low damping from 300K to 30mK, with $\alpha = 4.29 \times 10^{-5}$ at room temperature, comparable to the best YIG/GGG films. The diamagnetic substrate eliminates the dissipation mechanisms related to the paramagnetic GGG substrates.

To isolate the intrinsic magnon properties of YIG from the influence of GGG, we studied single-crystal YIG spheres with different impurity levels. By performing experiments on the purest YIG sphere cooled to 30 mK, we demonstrated the lifetimes of short-wavelength magnons exceeding 18 μs that is nearly two orders of magnitude longer than previously observed [9]. These findings overturn the established view of magnon dissipation limits, positioning magnons as viable, long-lived information carriers for solid-state quantum computing.

REFERENCES

[1]R. O. Serha, C. Dubs, and A. V. Chumak, *Magnetic materials for quantum magnonics*, arXiv 2510.09331 (2025).

[2]D. Lachance-Quirion, S. P. Wolski, Y. Tabuchi, et al., *Entanglement-based single-shot detection of a single magnon with a superconducting qubit*, Science **367**, 425–428 (2020).

[3]D. Xu, X.-K. Gu, H.-K. Li, et al., *Quantum control of a single magnon in a macroscopic spin system*, Phys. Rev. Lett. **130**, 193603 (2023).

[4]S. Knauer, K. Davídková, D. Schmoll, et al., *Propagating spin-wave spectroscopy in a liquid-phase epitaxial nanometer-thick yig film at millikelvin temperatures*, Journal of Applied Physics **133**, 143905 (2023).

[5]R. O. Serha, A. A. Voronov, D. Schmoll, et al., *Magnetic anisotropy and GGG substrate stray field in YIG films down to millikelvin temperatures*, npj Spintronics **2**, 29 (2024).

[6]R. O. Serha, A. A. Voronov, D. Schmoll, et al., *Damping enhancement in yig at millikelvin temperatures due to ggg substrate*, Materials Today Quantum **5**, 100025 (2025).

[7]D. Schmoll, A. A. Voronov, R. O. Serha, et al., *Wavenumber-dependent magnetic losses in yttrium iron garnet–gadolinium gallium garnet heterostructures at millikelvin temperatures*, Phys. Rev. B **111**, 134428 (2025).

[8]R. O. Serha, C. Dubs, C. Guguschev, et al., *Ysgag: the ideal substrate for yig in quantum magnonics*, arXiv 2508.19044 (2025).

[9]R. O. Serha, K. H. McAllister, F. Majcen, et al., *Ultra-long-living magnons in the quantum limit*, arXiv 2505.22773 (2025).

Multi-Mode Coupling in Magnon-Phonon Hybrids

Hans Huebl[1,*]

[1]Walther-Meißner-Institute, Bavarian Academy of Sciences, Garching, Germany

*contact: huebl@wmi.badw.de

The coupling of different degrees of freedom is a key ingredient of solid-state physics. Some questions, however, require the control over the coupling strength, which is typically realized in so-called hybrid systems. Here, the interaction between excitations, such as magnons, phonons, photons, or spins, are reliably engineered. Quantum sciences and applications harness these settings for information conversion, storage, sensing applications, or for investigating the quantum properties of these excitations. In addition, the hybrid systems are interesting from the perspective of novel functionalities arising from the emerging, mixed character of the participating modes.

In my presentation, I will discuss a hybrid system based on phonons and magnons. This system is interesting from a magnon-damping perspective, as phonons are considered a dominant magnon relaxation channel. Moreover, a large coupling between magnons and phonons can create a magnon-phonon hybrid. Thus, the magnons are expected to imprint the angular momentum properties onto the phonons, which is interesting in the context of phonon-mediated angular momentum transport. I will present our results on controlled magnon-phonon interaction using a heterostructure consisting of a magnetic thin film integrated in a phononic resonator.
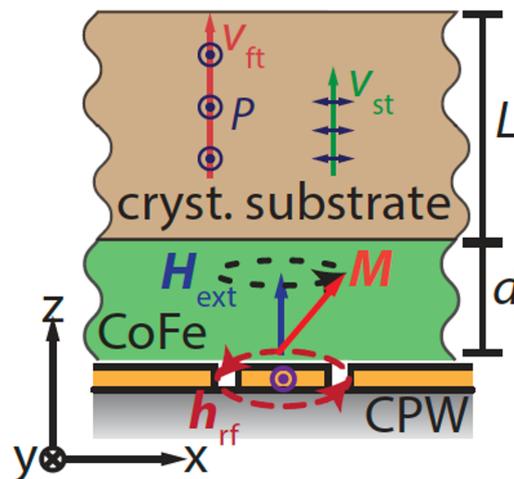

Figure 1: Magnon-phonon hybrids

Fabrication and Integration of Suspended YIG Micro Disk on Microwave Antennas

N. K. P. Babu [1,*], **J. Ben Youssef** [2], **O. Klein** [3], **Juan F. Sierra**[1], **Sergio O. Valenzuela** [1,4]

[1]Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and The Barcelona Institute
of Science and Technology (BIST), Campus UAB, Bellaterra, 08193 Barcelona, Spain
[2]LabSTICC, CNRS, Université De Bretagne Occidentale, 29238 Brest, France
[3]Université Grenoble Alpes, CEA, CNRS, Grenoble INP, Spintec, 38054 Grenoble, France
[4]Institució Catalana De Recerca I Estudis Avançats (ICREA), 08010 Barcelona, Spain

*contact: nandanbabu.kuttath@icn2.cat

Coherent microwave-to-optical transduction is a key remaining challenge for connecting quantum processors, working at GHz frequencies, to optical communication networks. Recently, optimal broadband transduction has been proposed using YIG-based magneto-mechanical structures, where magnetic and mechanical excitations mediate microwave-to-optical frequency conversion [1]. However, realizing practical devices requires YIG structures that can be integrated on chip with superconducting resonators without degrading microwave coherence. An important obstacle is that epitaxial YIG films are commonly grown on gadolinium gallium garnet (GGG), whose strong low-temperature paramagnetism can generate dissipation and compromise the resonator performance.

Here we implement and optimise a focused ion-beam (FIB) micro-machining and transfer/integration process [2] to fabricate suspended YIG micro-disks and place them directly onto microwave antennas and coplanar waveguide structures (Fig. 1). This fabrication process allows us to separate YIG from the GGG substrate, enabling integration onto selected low-loss substrates that preserve the superconducting resonator quality factors. This modular platform is compatible with on-chip magnon-photon coupling [1] and therefore provides a practical route towards hybrid superconducting-magnonic-photonic architectures for coherent microwave-to-optical transduction.
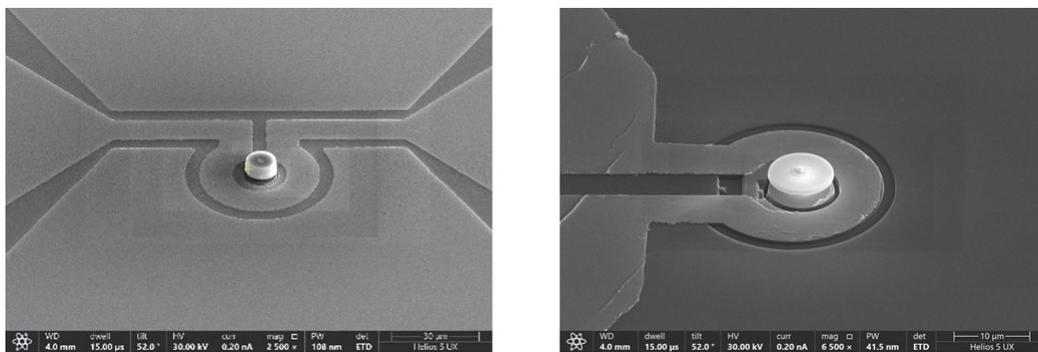

Figure 1: SEM image of the YIG disk integrated on a coplanar waveguide with Ω-loop (left), Ω- loop microstrip (right)

REFERENCES

[1]F. Engelhardt, V. Bittencourt, H. Huebl, O. Klein, and S. V. Kusminskiy, *Optimal broadband frequency conversion via a magnetomechanical transducer*, Phys. Rev. Appl. **18**, 044059 (2022).

[2]P. G. Baity, D. A. Bozhko, R. Macêdo, et al., *Strong magnon–photon coupling with chip-integrated yig in the zero-temperature limit*, Applied Physics Letters **119**, 033502 (2021).

Superconducting Diode Effect

Teruo Ono[1,2,3*]

[1]Institute for Chemical Research, Kyoto University, Japan
[2]Center for Spintronics Research Network, Kyoto University, Japan
[3]International Center for Synchrotron Radiation Innovation Smart, Tohoku University, Japan

*contact: ono@scl.kyoto-u.ac.jp

We found the superconducting diode effect (SDE) in Nb/V/Ta super-lattices with a polar structure, which is the ultimate diode effect exhibiting a superconducting state in one direction and a normal state in the other [1–3]. The SDE can be considered as the non-reciprocity of the critical current for the metal-superconductor transition. We have also found the reverse effect, i.e., the nonreciprocal critical magnetic field under the application of super-current [4]. We also found that the polarity of the superconducting diode shows a sign reversal when the magnetic field is increased [5]. Recently, we have succeeded in demonstrating zero-field SDE by introducing ferromagnetic layers into super-lattices [6, 7]. The polarity of the SDE is controlled by the magnetization direction of the ferromagnetic layer, leading to the development of novel non-volatile memories and logic circuits with ultra-low power consumption. This work was partly supported by JSPS KAKENHI Grant Numbers (18H04225, 18H01178, 18H05227, 20H05665, 20H05159, 21K18145), MEXT Initiative to Establish Next-generation Novel Integrated Circuits Centers (X-NICS) Grant Number JPJ011438, the Cooperative Research Project Program of the Research Institute of Electrical Communication, Tohoku University, and the Collaborative Research Program of the Institute for Chemical Research, Kyoto University.

REFERENCES

[1]F. Ando, D. Kan, Y. Shiota, et al., *Fabrication of noncentrosymmetric nb/v/ta superlattice and its superconductivity*, Journal of the Magnetics Society of Japan **43**, 17–20 (2019).

[2]F. Ando, Y. Miyasaka, T. Li, et al., *Observation of superconducting diode effect*, Nature **584**, 373–376 (2020).

[3]F. Ando, R. Kawarazaki, M. Naritsuka, et al., *Investigation of the upper critical field in artificially engineered nb/v/ta superlattices*, Japanese Journal of Applied Physics **60**, 060902 (2021).

[4]Y. Miyasaka, R. Kawarazaki, H. Narita, et al., *Observation of nonreciprocal superconducting critical field*, Applied Physics Express **14**, 073003 (2021).

[5]R. Kawarazaki, H. Narita, Y. Miyasaka, et al., *Magnetic-field-induced polarity oscillation of superconducting diode effect*, Applied Physics Express **15**, 113001 (2022).

[6]H. Narita, J. Ishizuka, R. Kawarazaki, et al., *Field-free superconducting diode effect in noncentrosymmetric superconductor/ferromagnet multilayers*, Nature Nanotechnology **17**, 823–828 (2022).

[7]H. Narita, J. Ishizuka, D. Kan, et al., *Magnetization control of zero-field intrinsic superconducting diode effect*, Advanced Materials **35**, 10.1002/adma.202304083 (2023).

Coherent Control of Magnons

Yi Li[1,*]

[1]Materials Science Division, Argonne National Laboratory, USA

*contact: yili@anl.gov

Magnons, the quanta of collective spin excitations in magnetically ordered media, exhibit unique features for microwave quantum engineering, with examples of non-reciprocity in the form of propagating spin wave, highly desired for noise-isolated qubit operations with on-chip integration, and magneto-optical coupling for microwave-to-optic transduction, highly desired for implementing quantum transduction and building quantum interconnects. For either purpose, the capability of coherent magnon control in the time domain is crucial for designing coherent magnon gate operations and extending the dynamic control into the quantum regime.

In the first part, we introduce how to coherently control magnons in single-crystal YIG spheres embedded in a coplanar superconducting resonator. Particularly, we demonstrate single-shot magnon pulse interference between two remotely coupled $Y_3Fe_5O_{12}$ (YIG) spheres embedded in a superconducting resonator [1]. We realize real-time constructive and destructive magnon interference by precisely controlling the frequency and time delay of two consecutive microwave pulses applied to one YIG sphere. In addition, we show a diffraction-grating-like interference pattern using up to four consecutive magnon pulses, where the interference peak becomes increasingly enhanced and sharpened with the number of pulses. Our results reveal that magnons can preserve full coherence, while being transferred between distant magnetic resonators. This is a critical requirement for implementing coherent magnon gate operations in real time.

In the second part, we demonstrate strong coupling to propagating spin wave in epitaxial YIG thin films grown on cryogenic-compatible $Y_3Sc_2Ga_3O_{12}$ (YSGG) substrates. By fabricating quarter-wavelength NbN superconducting resonators on the YIG film, we show strong coupling of microwave photon in the resonator to the Damon-Eshbach ($k \perp M$) and Backward Volume ($k \parallel M$) spin wave modes in the YIG film. Our results introduce the first all-on-chip superconducting hybrid magnonic circuit base on low-damping YIG thin films, which will become the next-generation circuit platform for exploring propagating-magnon-based quantum information science.

REFERENCES

[1]M. Song, T. Polakovic, J. Lim, et al., *Single-shot magnon interference in a magnon-superconducting-resonator hybrid circuit*, Nature Communications **16**, 3649 (2025).

Hybrid Magnon–Phonon Phenomena in Magnetic-Insulator/Piezoelectric Heterostructures

Katharina Lasinger[1,2,*], **Kevin Künstle**[2], **Yannik Kunz**[2], **John F. Gregg**[1], **Mathias Weiler**[2]

[1]Department of Physics, University of Oxford, United Kingdom
[2]Department of Physics and Landesforschungszentrum OPTIMAS, RPTU Kaiserslautern-Landau, Germany
*contact: katharina.lasinger@physics.ox.ac.uk

Magnetic-insulator–piezoelectric heterostructures have emerged as a versatile platform for studying hybrid magnonic–phononic phenomena with very low dissipation. Among these, YIG/ZnO heterostructures serve as a model system in which our recent work has established key ingredients for hybrid magnonics.

First, we demonstrated the generation and characterization of gigahertz surface acoustic waves (SAWs) [1], and showed that high-quality SAW propagation can be achieved on YIG, while its magnetic properties are preserved through the deposition of piezoelectric ZnO by RF sputtering. Second, we showed efficient SAW-driven excitation of spin waves in ultralow-damping YIG [2], revealing anisotropic and nonreciprocal magnetoelastic coupling. Third, resonator-based structures enabled the formation of a tunable magnon-polaron cavity and the demonstration of strong coupling [3], evidenced by clear avoided crossings, as shown in Figure 1.

Beyond ferrimagnetic YIG, the control of antiferromagnetic materials in real-world devices has the potential to advance current magnonics technology, by combining high resonance frequencies for faster operation with stability against external fields for improved robustness. As a first step toward this goal, we demonstrate tunable propagation of SAWs within an antiferromagnetic heterostructure consisting of α-Fe_2O_3 (hematite) and ZnO, and employ these phononic excitations to probe the antiferromagnetic phase transition in the system [4].

Our measurements demonstrate gigahertz SAW excitation, efficient magnetoelastic driving of finite-wavelength magnons, and tunable coupling, confirming the suitability of ZnO-based heterostructures for engineered magnon–phonon interactions.
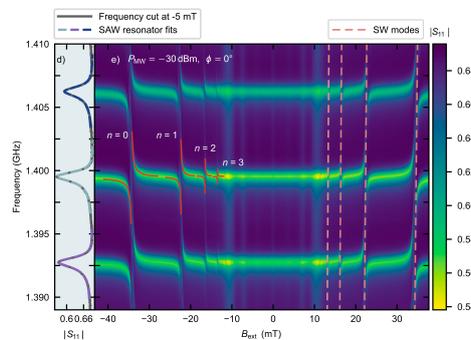

Figure 1: Adopted from [3] - SAW resonators on YIG/ZnO: d) $|S_{11}|$ reflection parameter of the uncoupled resonator. e) $|S_{11}|$ reflection parameter as a function of frequency and B_{ext}. Anticrossing positions align with calculated spin wave modes (light red dashed lines).

REFERENCES

[1]F. Ryburn et al., *Generation of gigahertz-frequency surface acoustic waves in $Y_3Fe_5O_{12}$/ZnO heterostructures*, Physical Review Applied **23** (2025).

[2]Y. Kunz et al., *Efficient spin-wave excitation by surface acoustic waves in ultralow-damping yttrium iron garnet–zinc oxide heterostructures*, Physical Review Applied **24** (2025).

[3]K. Künstle et al., *Magnon-polaron control in a surface magnetoacoustic wave resonator*, Nature Communications **16** (2025).

[4]K. Lasinger et al., *Tunable surface acoustic wave propagation and phase-transition probing in antiferromagnetic α-Fe_2O_3/ZnO heterostructures*, In preparation (2025).

Weak Coupling between Spin-Wave and Mechanical Modes of Suspended YIG Microdisks

Grégoire De Loubens[1,*], **Gabriel Soares**[1,2], **Rafael Lopes Seeger**[2], **Hugo Merbouche**[1], **Jamal Ben Youssef**[3], **Nandan Babu**[4], **Sergio Valenzuela**[4], **Seth Kurfman**[5], **Goerg Schmidt**[5], **Giovanni Olivetti**[2,6], **Thierry Valet**[6], **Benjamin Pigeau**[2], **Olivier Klein**[6]

[1]SPEC, CEA, CNRS, Université Paris-Saclay, France
[2]Institut Néel, CNRS, Université Grenoble Alpes, Grenoble, France
[3]LabSTICC, CNRS, Université De Bretagne Occidentale, France
[4]Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and BIST, Spain
[5]Martin Luther Universität Halle-Wittenberg - Institut Für Physik, Germany
[6]Université Grenoble Alpes, CEA, CNRS, Grenoble INP, Spintec, France

*contact: gregoire.deloubens@cea.fr

The magneto-elastic interaction couples the magnetic and elastic degrees of freedom, allowing spin-waves (SWs) and ultrasonic waves to hybridize [1]. YIG exhibits moderate magneto-elasticity and very low SW damping and acoustic losses, which can result in strong magnon-phonon coupling in single-crystalline samples [2]. With recent advances in the nanofabrication of YIG nanoresonators [3], it can be envisioned to couple SW dynamics to mechanics in such systems. An interesting practical aspect is to efficiently actuate the mechanical modes of YIG microstructures in the gigahertz range by inductively driving their SW modes. A longer-term perspective is to achieve the strong coupling regime between microwave photons, magnons, and phonons, which would enable broadband and coherent frequency conversion using this type of magneto-mechanical transducer [4].

Here, we present the mechanical and magnetic characterizations in the microwave range of suspended YIG microdisks obtained by two distinct methods: a bottom-up approach, where inductive elements are patterned near existing suspended YIG micro-disks [3], and a top-down one, where FIB manufactured YIG micro-rings are transferred directly into existing inductive antennas on arbitrary substrates (Fig. 1). To characterize their mechanical modes, we use a homemade laser Michelson interferometer. Many of them can be identified below 1 GHz. They exhibit quality factors of a few hundreds at ambient temperature and pressure. Damping coefficients as low as 10^{-4} are extracted from SW spectroscopy using MRFM. Signatures of weak coupling between SW and mechanical modes are also observed.
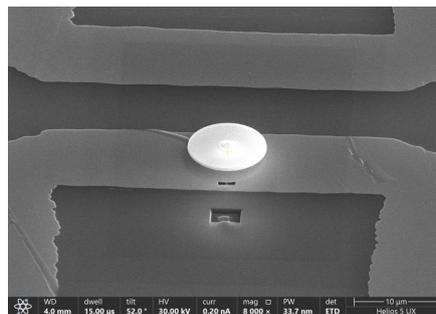

Figure 1: SEM picture of a suspended YIG micro-ring prepared by top-down approach.

REFERENCES

[1] C. Kittel, *Interaction of spin waves and ultrasonic waves in ferromagnetic crystals*, Phys. Rev. **110**, 836–841 (1958).

[2] K. An, A. N. Litvinenko, R. Kohno, et al., *Coherent long-range transfer of angular momentum between magnon kittel modes by phonons*, Phys. Rev. B **101**, 060407 (2020).

[3] F. Heyroth, C. Hauser, P. Trempler, et al., *Monocrystalline freestanding three-dimensional yttrium-iron-garnet magnon nanoresonators*, Phys. Rev. Applied **12**, 054031 (2019).

[4] F. Engelhardt, V. Bittencourt, H. Huebl, O. Klein, and S. V. Kusminskiy, *Optimal broadband frequency conversion via a magnetomechanical transducer*, Phys. Rev. Applied **18**, 044059 (2022).

Synthetic Motion of Magnon-Polaritons in Metamaterials

Satosh Tomita[1,*]

[1]Institute for Excellence in Higher Education, and Department of Physics, Tohoku University, Sendai, Japan
*contact: tomita@tohoku.ac.jp

Generating and identifying complex quasiparticles with elementary excitations is a classical issue, but it is still at the forefront of condensed matter physics and material science. Therefore, it comes as no surprise that complex quasiparticles referred to as magnon-polaritons (MPs), in which quantized spin waves in magnetic materials (magnons) are coupled to photons, stimulate a flurry of interest and hold great promise for realizing novel hybrid quantum systems. MPs generated in metallic or superconducting cavities for microwaves are reciprocal. However, nonreciprocity is highly required in sensitive signal detection and processing, particularly in the quantum regime.

In this talk, we study the nonreciprocity of MPs in a man-made photonic structure, referred to as a magneto-chiral (MCh) metamolecule consisting of a polycrystalline yttrium-iron garnet (YIG) cylinder as a magnetic meta-atom inserted into a right-handed helix made of copper (Cu) as a chiral meta-atom [1]. X-band microwave transmission spectra of the metamolecule with broken space-inversion and time-reversal symmetries simultaneously in a waveguide under DC external magnetic fields at room temperature (Fig. 1(a)) show anti-crossing and large Rabi-like splitting, indicating the ultrastrong coupling in MPs. Furthermore, microwave one-way transparency is observed in Fig. 1(b). These experimental results are reproduced via numerical simulations. Based on effective polarizability tensor analyses [2], we verify that the one-way transparency is caused by massive synthetic motion of MPs due to the combination of chiral-type bianisotropy by the Cu helix and magneto-optical effects by the YIG cylinder [3]. This study bridges the gap between the cavity magnonics and microwave photonics via metamaterials, and signifies an advancement toward spintronic hybrid quantum systems for quantum computing and synthetic gauge fields acting on light using chimera quasiparticles [4].
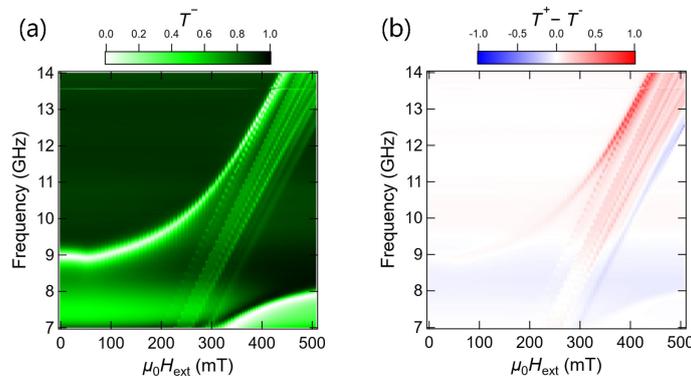

Figure 1: 2D plots of experimentally observed (a) transmittance (T^-) and (b) nonreciprocity ($T^+ - T^-$) of the MCh metamolecule as a function of external DC magnetic field ($\mu_0 H_{\text{ext}}$, horizontal) and frequency (vertical) [3].

REFERENCES

[1]K. Mita, T. Chiba, T. Kodama, et al., *Ultrastrongly coupled and directionally nonreciprocal magnon polaritons in magnetochiral metamolecules*, Phys. Rev. Appl. **23**, L011004 (2025).

[2]T. Kodama, T. Nakanishi, K. Sawada, and S. Tomita, *Pure moving optical media consisting of magnetochiral metasurfaces*, Opt. Mater. Express **14**, 2499–2513 (2024).

[3]K. Mita, T. Kodama, T. Nakanishi, et al., *Microwave one-way transparency by large synthetic motion of magnetochiral polaritons in metamolecules*, arXiv 2503.22279.

[4]T. Kodama, N. Kikuchi, T. Chiba, et al., *Magnetic permeability time-varying metamaterials at microwave frequencies*, arXiv 2503.04571.

Acoustic-Mechanical Hybrid Resonance for Enhanced Magnon-Phonon Coupling

Yukio Nozaki[1,2,*] **and Kazuto Yamanoi**[1]

[1]Department of Physics, Keio University, Japan
[2]CSRN, Keio University, Japan

*contact: nozaki@phys.keio.ac.jp

We focus on the efficient synthesis of magnon–phonon hybrid systems, commonly referred to as chimera quasi-particles. Despite extensive research into coupling via magnetoelastic interaction,[1] the relatively short magnon lifetime compared to phonons remains a key barrier to realizing such hybrid excitations. Our approach addresses this by investigating methods to boost magnon excitation. We achieve this by generating AC spin currents (AC-SC) through Surface Acoustic Waves (SAWs) or the mechanical resonance of microfabricated structures, utilizing the gyromagnetic effect. The resulting spin-transfer torque (STT) enhances magnon excitation, thereby facilitating stronger coupling with phonons.

The gyromagnetic effect links macroscopic rotation and magnetization. While rigid-body rotation is limited to approximately 100 kHz, SAWs can generate localized rotation (vorticity) at GHz frequencies. Rayleigh-type SAWs generate a periodic AC Barnett field that decays exponentially along the film thickness. Based on the Spin Vorticity Coupling (SVC) theory, the gradient of this Barnett field is predicted to generate a flow of electron spin, i.e., spin current.[2] This AC-SC is non-uniform, changing in amplitude and polarity both temporally and spatially as the SAW propagates. We experimentally detected this AC-SC by measuring SAW attenuation in Nonmagnetic (NM) / Ferromagnetic (FM) bilayers (NM = Cu, Ti, Pt; FM = NiFe) on a piezoelectric substrate[3, 4]. The generated AC-SC in the NM layer injects into the adjacent FM layer, causing a periodic AC-STT and subsequent excitation of spin waves (SWs). Energy balance dictates that the damping of SWs in NiFe results in measurable SAW attenuation. We observed strong SAW attenuation when the SW resonance (SWR) condition was satisfied in the Cu/NiFe bilayer. Critically, the attenuation was strongest using highly conductive Cu, supporting the SVC prediction that the gyromagnetic spin torque is robust against the strength of the Spin-Orbit Interaction (SOI). Furthermore, utilizing higher-order SAW harmonics allowed us to demonstrate effective SW excitation across a wideband range (0.1–10 GHz), suggesting that higher frequencies enhance the effect.

To further boost the acoustic gyromagnetic effect, we performed a numerical analysis of the coupling between SAWs and the mechanical resonance of honeycomb nanopillar arrays.[5] Calculations for Ta nanopillars on a $LiNbO_3$ substrate revealed a precession mode at $\approx$1.6 GHz and a key coupled resonance mode at $\approx$1.8 GHz that is strongly associated with large surface vibration of the LN substrate. To quantify the boosting effect caused by the spin current generation, we calculated the frequency dependence of the volume-averaged gradient of the vorticity. A boosting effect was observed across the frequency range, with the strongest enhancement appearing precisely at 1.8 GHz. This maximum boost correlates directly with the frequency where the LN surface vibration and the pillar mechanical resonance are maximally coupled. These results demonstrate that appropriately tuned acoustic-driven mechanical resonance offers a highly efficient pathway for spin-wave excitation, moving us closer to achieving magnon–phonon hybrid excitations.

REFERENCES

[1]M. Weiler, L. Dreher, C. Heeg, et al., *Elastically driven ferromagnetic resonance in nickel thin films*, Phys. Rev. Lett. **106**, 117601 (2011).

[2]M. Matsuo, J. Ieda, K. Harii, E. Saitoh, and S. Maekawa, *Mechanical generation of spin current by spin-rotation coupling*, Phys. Rev. B **87**, 180402 (2013).

[3]D. Kobayashi, T. Yoshikawa, M. Matsuo, et al., *Spin current generation using a surface acoustic wave generated via spin-rotation coupling*, Phys. Rev. Lett. **119**, 077202 (2017).

[4]Y. Kurimune, M. Matsuo, S. Maekawa, and Y. Nozaki, *Highly nonlinear frequency-dependent spin-wave resonance excited via spin-vorticity coupling*, Phys. Rev. B **102**, 174413 (2020).

[5]Y. Nii and Y. Onose, *Imaging an acoustic topological edge mode on a patterned substrate with microwave impedance microscopy*, Phys. Rev. Appl. **19**, 014001 (2023).

Fabrication of Magnetic Garnet Thin Film, Microstructured, and Free-Standing Heterostructures via Room-Temperature Pulsed Laser Deposition

Seth W. Kurfman[1,*]

[1]Institut Für Physik, Martin Luther Universität Halle-Wittenberg, Germany

*contact: seth.kurfman@physik.uni-halle.de

YIG has long held the position as the gold standard material for low-loss magnonics due to its high-Q magnetic resonance. Further, its acoustic, optical, and magnetostrictive properties in bulk systems and in high-quality films grown on lattice-matched substrates (e.g. GGG) have led to demonstrations of coherent strong coupling between YIG magnons and photons, phonons, superconducting resonators, and spins [1]. In particular, high-quality micro- and nanostructures of YIG are geometrically attractive for minimizing the lateral size of practical integrated devices, in addition to providing access to higher order magnetic, acoustic, and optical modes due to confinement effects [2]. Further, by exploiting the magnetostrictive nature of YIG, selective choices of the growth substrate or lattice-site substitution can dramatically tune the magnetic anisotropy of films and patterned structures [3]. Recent efforts into growing high-quality YIG on garnets free of rare-earth ions has enabled the direct on-chip integration of superconducting resonators with the garnet substrates [4]. However, most deposition techniques rely on the fabrication of films at high-temperatures followed by etching to create microstructures which contributes to increase losses in the YIG structures and resonators due to etching-induced roughness and damage to the YIG material. The successful development high-quality YIG films acquired from room-temperature pulsed laser deposition (RT PLD) of YIG films followed by a high-temperature anneal [5] has enabled the use of standard lift-off processes without the need ion etching processes to produce fixed and free-standing suspended microstructures of YIG that exhibit exceptional high-quality (low loss) magnetic resonance properties [6, 7]. Standard processes to fabricate high-quality, sintered PLD targets allows the straightforward replacement of YIG with other magnetic garnets for deposition, and the use of various garnet substrates allows for a rapid exploration of the available material phase space. The use of this RT PLD technique with post-anneal has, to date, remained relatively unexplored with other garnets besides YIG on GGG substrates. Here, we discuss the straightforward extension of this RT PLD technique and show that it enables the growth of a variety of high-quality magnetic garnet thin films on various non-magnetic garnet substrates, even without extensive optimization of the growth parameters. In the talk, we consider how the magnetic anisotropy and effective magnetization of YIG thin films is altered through strain by altering the garnet substrate or by depositing substituted-YIG (s-YIG) material. Finally, we show that the post-growth annealing process allows the fabrication of multi-layer YIG/s-YIG thin films and suspended microstructured garnet heterostructures.

REFERENCES

[1] D. Lachance-Quirion, Y. Tabuchi, A. Gloppe, K. Usami, and Y. Nakamura, *Hybrid quantum systems based on magnonics*, Applied Physics Express **12**, 070101 (2019).

[2] K. O. Nikolaev, S. R. Lake, G. Schmidt, S. O. Demokritov, and V. E. Demidov, *Resonant generation of propagating second-harmonic spin waves in nano-waveguides*, Nature Communications **15**, 10.1038/s41467-024-46108-y (2024).

[3] W. Legrand, Y. Kemna, S. Schären, et al., *Lattice-tunable substituted iron garnets for low-temperature magnonics*, Advanced Functional Materials **36**, 10.1002/adfm.202503644 (2025).

[4] S. Guo, D. Russell, J. Lanier, et al., *Strong on-chip microwave photon–magnon coupling using ultralow-damping epitaxial y3fe5o12 films at 2 k*, Nano Letters **23**, 5055–5060 (2023).

[5] C. Hauser, T. Richter, N. Homonnay, et al., *Yttrium iron garnet thin films with very low damping obtained by recrystallization of amorphous material*, Scientific Reports **6**, 10.1038/srep20827 (2016).

[6] F. Heyroth, C. Hauser, P. Trempler, et al., *Monocrystalline freestanding three-dimensional yttrium-iron-garnet magnon nanoresonators*, Physical Review Applied **12**, 10.1103/physrevapplied.12.054031 (2019).

[7] P. Trempler, R. Dreyer, P. Geyer, et al., *Integration and characterization of micron-sized yig structures with very low gilbert damping on arbitrary substrates*, Applied Physics Letters **117**, 10.1063/5.0026120 (2020).

Phonon Parametric Pumping for Magnonics

Albrecht Jander[1,*], **Pallavi Dhagat**[1,], **Carson Rivard**[1], **Bennett Pohlmann**[1]

[1]School of Electrical Engineering and Computer Science, Oregon State University, USA

*contact: jander@oregonstate.edu

Magnonics—the processing of information carried by spin waves—offers a low-power alternative to electronics for microwave signal processing and wave-based computation. Here we explore phonon–magnon parametric interactions as a mechanism for realizing nonlinear and active functions in magnonic circuits. Such processes enable (i) the *generation* of magnons with defined wave vector and mode [1], (ii) *amplification* of propagating spin-wave signals [2], and (iii) *frequency translation* and *beam steering* of spin-waves.

Magnetoelastic coupling in materials such as yttrium-iron-garnet (YIG) mediates the stimulated parametric down-conversion of a phonon into two magnons. As illustrated in Figure 1a, one of the resulting magnons adds to and amplifies the stimulating "signal" spin wave while the second "idler" magnon is created to balance the energy and momentum of the absorbed phonon.
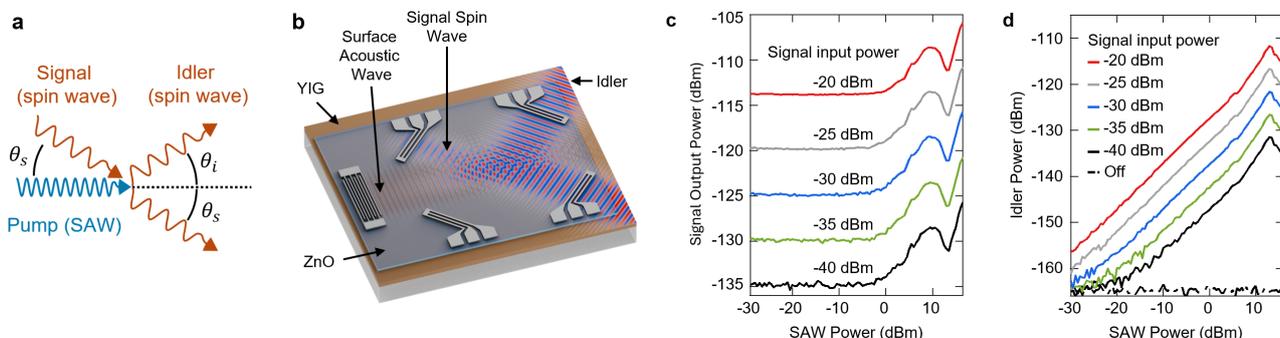
Figure 1: (a) Schematic phonon pumping of magnons; (b) Structure of experimental devices; (c) SAW-pumped amplification of spin-wave transmission; (d) Idler power as a function of pump power and signal input power.

Using the device illustrated in Figure 1b, we have experimentally demonstrated the sustained amplification of coherent spin waves introduced in YIG films via inductive transducers; as well as phonon-pumped parametric amplification of stochastic magnons from the thermal background. The transmission spectra in Figure 1c show up to 6 dB of amplification by a traveling surface acoustic wave (SAW) pump. Concurrently, idler magnons, generated at the corresponding wave vector, are detected at a separate transducer. The idler power (Figure 1d) scales bilinearly with both the signal and pump powers, consistent with three-wave mixing theory. The same interaction is observed at different incidence angles, subject to the availablility of magnon states that allow for idler wave vectors satisfying momentum and energy conservation.

At higher pump powers, stochastic magnons excited from the thermal background are also observed, a process sometimes described as parametric *generation*. However, beyond a critical pump power, this ultimately leads to parametric instability. We note that the 6 dB gain shown in Figure 1c is achieved at 10 dBm pump power, which is below the threshold for parametric instability.

In further experiments, in the case of non-degenerate pumping, we observe the parametric excitation of magnons at new frequencies, translated from the coherent signal, which can be directed into different propagation angles or spin-wave modes depending on the vector relation between the signal and pump.

REFERENCES

[1]C. Rivard, A. Jander, and P. Dhagat, *Parametric instability of forward volume spin waves pumped by surface acoustic waves in yttrium iron garnet films*, Applied Physics Letters **127**, 042408 (2025).

[2]C. Rivard, A. Jander, and P. Dhagat, *Sustained amplification of coherent spin waves by parametric pumping with surface acoustic waves*, npj Spintronics (in press).

Phonon-Assisted Generation of Propagating Quantum Magnonic States

Carlos Gonzalez Ballestero[1,*]

[1]Institute for Theoretical Physics, Vienna University of Technology (TU Wien)

*contact: carlos.gonzalez-ballestero@tuwien.ac.at

Preparing certifiably quantum states of magnons represents a central milestone in the emerging field of quantum magnonics. Among these, Gaussian states are particularly attractive, as they can be prepared and manipulated without direct coupling to qubits, thereby allowing a wide range of current solid-state experiments to access the quantum regime. We have recently proposed and analyzed a protocol to generate such states – specifically, vacuum-squeezed and entangled states – in the ferromagnetic resonance mode of anisotropic yttrium iron garnet (YIG) samples [1]. We further demonstrate how these states can be certified using state-of-the-art measurement techniques.

Building on these results, the preparation of quantum states of propagating magnons in continuum structures remains an outstanding challenge. One promising route involves spontaneous parametric down-conversion, where intrinsic nonlinear three-magnon processes lead to the splitting of a magnon into an entangled pair. However, these processes are often shadowed by four-magnon interactions which introduce strong dephasing and decoherence, severely limiting the feasibility of this approach.

We propose an alternative route that harnesses the strong nonlinear magnon–phonon coupling, specifically exploiting the parametric process of phonon decay into two magnons. We develop a comprehensive continuum classical and quantum theoretical framework and use it to identify and predict the thresholds for parametric instabilities of all nonlinear processes arising in thin-film geometries [2]. Our analysis reveals that in suitably engineered samples, phonon-to-magnon parametric down-conversion can occur at significantly lower thresholds than purely magnonic nonlinearities, thereby enabling access to quantum correlations without triggering four-magnon-induced dephasing. Our theoretical model has been verified by observing phonon-to-magnon down-conversion in the classical regime [3]. We theoretically predict that in the quantum regime the same mechanism allows for the generation of entanglement between propagating magnons at cryogenic temperatures, and propose methods to detect such entanglement in current magnonic experiments.

REFERENCES

[1]M. Mycroft, R. Serha, A. V. Chumak, and C. Gonzalez-Ballestero, *In preparation*, (2025).

[2]M. Brühlmann, Y. Hwang, J. Puebla, and C. Gonzalez-Ballestero, *Classical and quantum theory of magnonic and magnetoelastic nonlinear dynamics in continuum geometries*, arXiv preprint, arXiv:2509.16199 (2025).

[3]Y. Hwang, L. Liao, J. Puebla, et al., *Harmonic and subharmonic magnon generation in a surface acoustic wave resonator*, arXiv preprint, arXiv:2509.19706 (2025).

Generation of Magnon Polaron in Strongly Coupled Cavity Magnomechanical System

Daiki Hatanaka[1,*], Motoki Asano[1], Megumi Kurosu[1], Yoshitaka Taniyasu[1], Hajime Okamoto[1], Hiroshi Yamaguchi[1]

[1]Basic Research Laboratories, NTT, Inc., Japan

*contact: daiki.hatanaka@ntt.com

Hybridized quasiparticles formed by strong coupling between magnons and phonons (magnon polarons) host characteristics arising from both magnonic and phononic natures. This hybridization enables novel functionalities such as nonreciprocal phonon transport and magnetic-field tuning of acoustic properties. The strong coupling has previously been demonstrated only in surface acoustic wave (SAW)-based magnomechanical systems by increasing the operation frequency to $\omega_a/2\pi$ = 6.5 GHz because of the general relationship of a coupling strength with frequency, $g \propto V_{ov}\sqrt{\omega_a}$ (V_{ov}: overlap mode volume) [1]. Although promising, the fabrication difficulty of such a super high frequency SAW structure limits the versatility and scalability of magnomechanical systems.

In this work, we demonstrated strong magnon-phonon coupling and the formation of magnon polarons in a cavity magnomechanical system operating at a moderate frequency of $\omega_a/2\pi$ = 0.9 GHz, which was made possible by increasing a magnon-phonon mode overlap (V_{ov}) instead of ω_a [2]. A SAW resonator was fabricated on an aluminum nitride (AlN) film deposited on a YIG/GGG substrate (Fig. 1). SAWs were excited piezoelectrically via an interdigital transducer (IDT) and confined between Bragg reflectors to form a resonance. A static magnetic field ($\mu_0 H_{ex}$) was applied parallel to the propagation direction of the SAWs, and the field-dependent transmission spectra $|S_{21}|^2$) were electrically measured at the other IDT (Fig. 2). Distinct avoided crossings were observed around ±14 mT and ±24 mT, indicating strong coupling of phonons to fundamental ($l = 0$) and 1st-order ($l = 1$) magnon modes, respectively. Comparison with theoretical calculations confirms that the coupling rate exceeds both magnonic and acoustic dissipation rates ($g > \kappa_a, \kappa_m$), verifying the stabilization of magnon polarons. Our demonstration establishes a pathway toward magnetic control of phonons at moderate frequencies, providing a foundation for phonon-based microwave signal processing technologies.
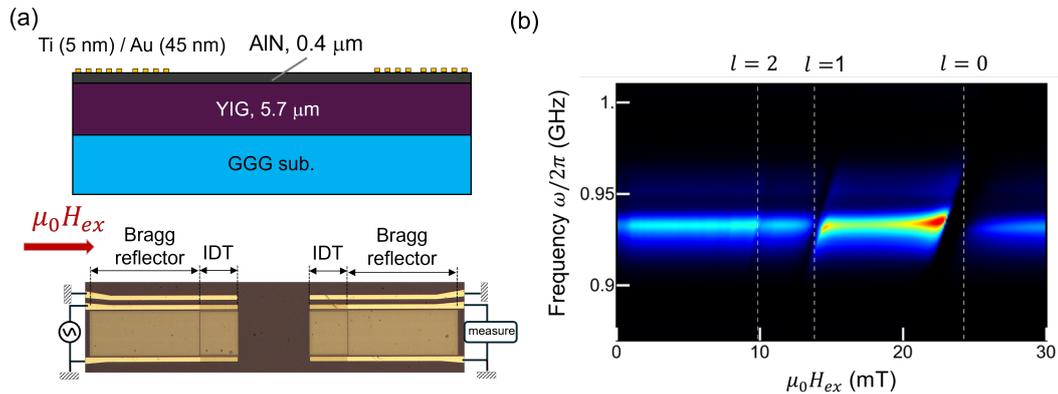
Figure 1: **(a)** Top: Schematic of the film structure AlN/YIG on a GGG substrate. Bottom: optical microscope image of SAW magnomechanical system. **(b)** External magnetic field amplitude ($\mu_0 H_{ex}$) dependence of the SAW resonant response.

REFERENCES

[1]Y. Hwang, J. Puebla, K. Kondou, et al., *Strongly coupled spin waves and surface acoustic waves at room temperature*, Physical Review Letters **132**, 10.1103/physrevlett.132.056704 (2024).

[2]D. Hatanaka, M. Asano, M. Kurosu, et al., *On-chip magnon-polaron generation in mode-matched cavity magnomechanics*, Physical Review Applied **24**, 10.1103/184d-4tgb (2025).

Self-Induced Floquet Magnons in Magnetic Vortices

Katrin Schultheiss[1,*], **Christopher Heins**[1], **Lukas Körber**[2], **Joo-Von Kim**[3], **Thibaut Devolder**[3], **Johan H. Mentink**[2], **Attila Kákay**[1], **Jürgen Fassbender**[1], **Helmut Schultheiss**[1]

[1]Helmholtz-Zentrum Dresden–Rossendorf, Institut Für Ionenstrahlphysik Und Materialforschung, Germany

[2]Radboud University, Institute of Molecules and Materials, Nijmegen, The Netherlands

[3]Centre de Nanosciences et de Nanotechnologies, CNRS, Université Paris-Saclay, France

*contact: k.schultheiss@hzdr.de

Magnetic vortices (Fig. 1a) are prototypical examples of topological textures in magnetism, characterized by a rich magnon spectrum as well as the eigen-resonance of the vortex texture itself, the gyration of its core. These two types of excitations are usually well separated in frequency: the vortex core typically gyrates in the sub-GHz range (Fig. 1b), while magnon eigenmodes appear in the lower GHz range (Fig 1c). This frequency separation provides a unique opportunity to study the interaction between collective spin-wave excitations and the time-periodic modulation of the magnetic ground state.

When the vortex core gyration is coherently driven, it imposes a temporal periodicity on the system that couples back to the magnon spectrum. In this driven regime, Floquet magnon bands emerge [1]. These energy states are shifted by integer multiples of the drive frequency, in close analogy to Bloch states in crystalline lattices. Our experimental results, corroborated by micromagnetic simulations, reveal how regular magnon modes (Fig. 1d) hybridize with this temporal lattice and transform into new Floquet states (Fig. 1e). These excitations are distinct from both the static magnon spectrum and the vortex core resonance, representing new quasiparticles in driven magnetic systems.

Beyond their fundamental interest, Floquet-engineered magnons display frequency comb formation, where resonant mode coupling generates a set of equidistant spectral lines. This effect provides a versatile mechanism for frequency down-conversion and broadband signal generation across the GHz range. These results illustrate how time- periodic driving can induce non-equilibrium states with novel dynamical properties, opening pathways for tailored spin dynamics and new functionalities in magnon-based information processing.
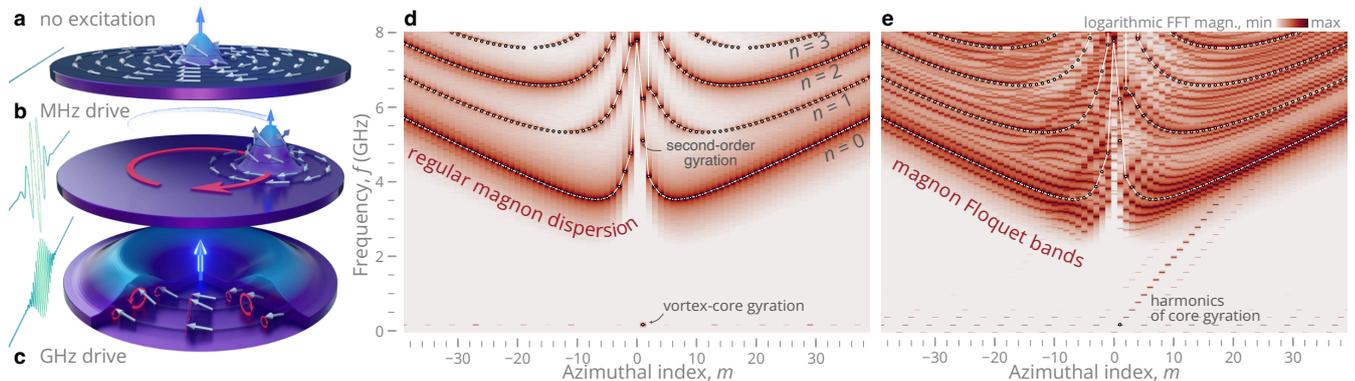

Figure 1: Schematic illustrations of (a) a static magnetic vortex, (b) a gyrating magnetic vortex driven by a MHz microwave signal, and (c) a magnon mode with lowest radial and azimuthal mode indices ($n = 0, m = 0$). Dimensions are not to scale. (d) Simulated dispersion of thermally populated magnon modes in the vortex with a static core plotted as a function of azimuthal mode index m for different radial indices n. (f) Micromagnetic simulations of the thermal magnon population in a gyrating vortex show the magnon Floquet bands.

REFERENCES

[1]C. Heins, L. Körber, J.-V. Kim, et al., *Self-induced Floquet magnons in magnetic vortices*, arXiv:2409.02583 [cond-mat], Sept. 2024.

Spin Mechanics with Ensembles of NV Centers in Diamonds

Gabriel Hétet[1,*], Louis Chambard[1], Maxime Perdriat[1]

[1]Laboratoire De Physique De L'École Normale Supérieure, École Normale Supérieure, PSL
Research University, CNRS, Sorbonne Université, Université Paris Cité , 24 Rue Lhomond, 75231
Paris Cedex 05, France
*contact: gabriel.hetet@ens.fr

Controlling the motion of trapped macroscopic particles in the quantum regime has been the subject of intense research in recent decades. Especially noteworthy is the recent milestone of achieving ground state cooling for a trapped particle [1, 2]. However, the generation of purely non Gaussian states such as the first phonon Fock state or Schrödinger cat states, is required for further quantum control as well as for realizing quantum interference. One approach is to transfer the quantumness of a well-controlled two-level system to the mechanical degree of freedom, which can be realized by coupling the motion of crystals with embedded spins using magnetic fields.

The coherence time of the spin system stands as a critical factor for this application in particular for the preservation of Schrödinger cat states, which is still a significant challenge in the field of levitodynamics.

We will show our progress towards this goal using electronic spins of NV centers in diamonds in Paul traps [3] as well as attached to a cantilever [4]. We will also show recent results on Nuclear Magnetic Resonance (NMR) within a levitating micro-diamond. There, we employ the nuclear spins of nitrogen-14 atoms, offering coherence times up to hundreds of microseconds. This represents the longest coherence time recorded for a controlled two-level system in a levitated particle, surpassing the previously measured coherence time in electronic spins by three orders of magnitude [5].

REFERENCES

[1]J. Piotrowski, D. Windey, J. Vijayan, et al., *Simultaneous ground-state cooling of two mechanical modes of a levitated nanoparticle*, Nature Physics **19**, 1009–1013 (2023).

[2]U. Delić, M. Reisenbauer, K. Dare, et al., *Cooling of a levitated nanoparticle to the motional quantum ground state*, Science **367**, 892–895 (2020).

[3]J. Voisin, A. Durand, T. Copie, M. Perdriat, and G. Hétet, *Nuclear magnetic resonance with a levitating microparticle*, Phys. Rev. Lett. **133**, 213602 (2024).

[4]M. Perdriat, A. Durand, L. Chambard, J. Voisin, and G. Hétet, *Spin-dependent force from an nv center ensemble on a microlever*, Phys. Rev. B **112**, 094419 (2025).

[5]T. Delord, P. Huillery, L. Nicolas, and G. Hétet, *Spin-cooling of the motion of a trapped diamond*, Nature **580**, 56–59 (2020).

To Be Determined

Aristide Lemaître[1,*], Second Author[1,2], Third Author[2]

[1]C2N, France
[2]Department Name, Institution 2, Country

*contact: aristide.lemaitre@universite-paris-saclay.fr

Magnon Superlattices around Skyrmions in Frustated Magnets

Christina Psaroudaki[1,*], Adarsh Hullahalli[1,2], Christos Panagopoulos[2]

[1]Laboratoire De Physique De L'École Normale Supérieure, ENS, Université PSL, CNRS, Sorbonne Université, Université De Paris, F-75005 Paris, France
[2]Division of Physics and Applied Physics, School of Physical and Mathematical Sciences, Nanyang Technological University, 637371 Singapore
*contact: christina.psaroudaki@phys.ens.fr

Chirality is a fundamental concept in physics, appearing in everything from particle properties to emergent quasiparticles such as skyrmions, topologically protected spin textures with twisted configurations defined by helicity. While helicity is typically fixed in chiral magnets, frustrated magnets offer a new platform where helicity becomes a free parameter, enabling richer excitation spectra and complex magnetization dynamics. In this talk, I present magnetic nano-skyrmions as candidates for quantum logic elements, focusing on their potential in quantum computing[1, 2]. I then turn to collective spin-wave excitations, where hybridization between internal skyrmion modes and magnons gives rise to dynamical magnon superlattices, interference patterns of localized spin waves[3]. In skyrmion lattices, these localized modes form complex magnonic bands with nontrivial Chern numbers, further enriched by long-range interactions. These findings reveal a rich interplay between frustration, topology, and dynamics, and open new directions for skyrmion-based magnonic devices beyond the conventional chiral paradigm.
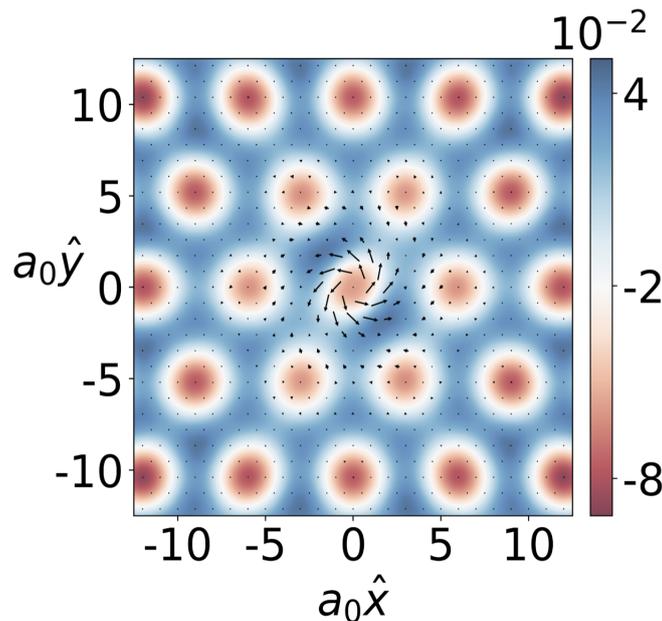

Figure 1: Magnon Superlattices around a single skyrmion in frustrated magnets.

REFERENCES

[1]C. Psaroudaki, E. Peraticos, and C. Panagopoulos, *Skyrmion qubits: challenges for future quantum computing applications*, Applied Physics Letters **123**, 260501 (2023).

[2]C. Psaroudaki and C. Panagopoulos, *Skyrmion qubits: a new class of quantum logic elements based on nanoscale magnetization*, Phys. Rev. Lett. **127**, 067201 (2021).

[3]A. Hullahalli, C. Panagopoulos, and C. Psaroudaki, *Magnon superlattices around skyrmions in frustrated magnets*, 2026.

Control and Readout of Single Nuclear Spins via Microwave Photon Counting

James O'Sullivan[1,*]**, Jaime Travesedo**[1]**, Louis Pallegoix**[1]**, Zhiyuan W. Huang**[1]**,
Patrick Hogan[2]**, Alexandre S. May**[1,3]**, Boris Yavkin**[1]**, Sen Lin**[4]**, Ren-Bao Liu**[4]**,
Thierry Chaneliere[5]**, Sylvain Bertaina**[6]**, Philippe Goldner**[7]**, Daniel Estève**[1]**, Denis Vion**[1]**,
Patrick Abgrall[1]**, Patrice Bertet**[1]**, Emmanuel Flurin**[1]

[1]Service De Physique De L'État Condensé (CNRS, UMR 3680),, IRAMIS, CEA-Saclay, Université Paris-Saclay, 91191 Gif-Sur-Yvette, France
[2]London Centre for Nanotechnology, UCL, 17-19 Gordon Street, London, WC1H 0AH, UK
[3]Alice&Bob, 53 Boulevard Du Général Martial Valin, 75015 Paris
[4]Department of Physics, Centre for Quantum Coherence, The State Key Laboratory of Quantum Information Technologies and Materials, and New Cornerstone Science Laboratory, The Chinese University of Hong Kong, Shatin, New Territories, Hong Kong, China
[5]Université Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, 38000 Grenoble, France
[6]CNRS, Aix-Marseille Univ. University of Toulon, IM2NP, 13013, Marseille, France
[7]Chimie ParisTech, PSL University, CNRS, Institut De Recherche De Chimie Paris, 75005 Paris, France
*contact: james.osullivan@cea.fr

I will present a platform for single electron and single nuclear spin spin detection and control, consisting of ^{183}W nuclear spins adjacent to an effective spin-1/2 Er^{3+} impurity in a $CaWO_4$ crystal. The Er^{3+} spin is coupled to a superconducting resonator. We also study a single ^{93}Nb spin-9/2 nucleus adjacent to an Er^{3+} spin. The state of the ^{183}W and ^{93}Nb nuclear spins influences the number of photons emitted after repeated excitation of the Er^{3+} electron spin, enabling quantum non-demolition readout using a single microwave photon detector. We use this system to study the properties of the nuclear spins, prepare an entangled state of two ^{183}W nuclear spins and reconstruct the relative positions of nuclear spins around the Er^{3+} impurity.
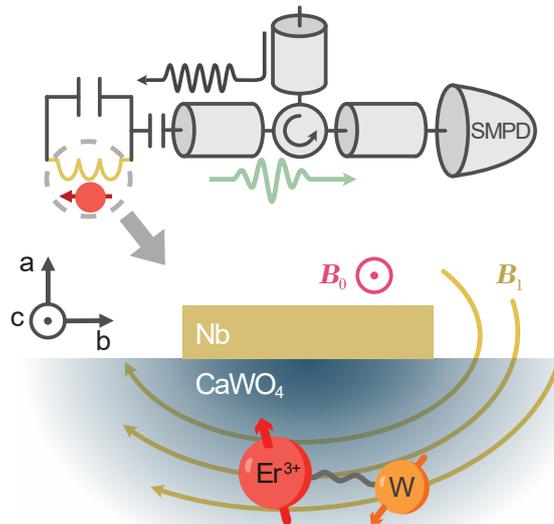

Figure 1: Schematic of the experiment showing a superconducting resonator (gold) coupled to an Er3+ defect (red) in turn coupled to a nearby W nuclear spin (orange). Fluorescence photons are detected via a circulator using a Single Microwave Photon Detector (SMPD).

Coupling of Electron-Spin and Nuclear-Spin Excitations

Hiroki Arisawa[1,2,*] **and Eiji Saitoh**[1,2,3,4]

[1]Department of Applied Physics, The University of Tokyo, Tokyo 113-8656, Japan.
[2]RIKEN Center for Emergent Matter Science, Wako 351-0198, Japan.
[3]Institute for AI and Beyond, The University of Tokyo, Tokyo 113-8656, Japan.
[4]WPI, Advanced Institute for Materials Research, Tohoku University, Sendai 980-8577, Japan.

*contact: h.arisawa@ap.u-tokyo.ac.jp

In solids, nuclear spins are usually well isolated and therefore difficult to manipulate directly with external fields. However, through the hyperfine interaction with electron spins, nuclear spins can be controlled indirectly, a mechanism that has been widely studied in nuclear-spin physics. More recently, nuclear spins have also attracted attention in spintronics, and nuclear spintronics phenomena, such as nuclear spin pumping effect [1] and nuclear spin Seebeck effect [2], have been investigated, leading to the emergence of nuclear spintronics [1–4].

In this study, we investigate the coupling between electron-spin and nuclear-spin excitations in $MnCO_3$ mediated by the hyperfine interaction. By performing microwave-spectroscopy measurements, we show that the electron-spin and nuclear-spin resonance modes strongly hybridize at low temperatures due to the hyperfine coupling. In this talk, we will introduce these coupled phenomena and discuss how the coupling may enable the use of nuclear-spin degrees of freedom as information carriers in spintronics.

REFERENCES

[1]Y. Shiomi, J. Lustikova, S. Watanabe, et al., *Spin pumping from nuclear spin waves*, Nat. Phys. **15**, 22 (2019).
[2]T. Kikkawa, D. Reitz, H. Ito, et al., *Observation of nuclear-spin seebeck effect*, Nat. Commun. **12**, 4356 (2021).
[3]T. Makiuchi, T. Kikkawa, T. Sichanugrist, et al., *Field dispersion and strong coupling of nuclear-electron spin excitation in $MnCO_3$*, Phys. Rev. Research **7**, 033083 (2025).
[4]J. D. M. de Lima, D. S. Maior, E. C. Souza, et al., *Giant nuclear-electronic spin pumping in the heisenberg antiferromagnet $RbMnF_3$*, Phys. Rev. Lett. **134**, 146702 (2025).

Electric Manipulation of Coupled Nuclear- and Electron-Spin Dynamics

Takashi Kikkawa[1,*]

[1]Advanced Science Research Center, Japan Atomic Energy Agency, Tokai 319-1195, Japan

*contact: kikkawa.takashi@jaea.go.jp

Nuclear spins, with their long coherence times, are fundamental to nuclear magnetic resonance (NMR) and magnetic resonance imaging (MRI), serving as powerful tools for probing microscopic properties of matter. In addition to having a spin angular-momentum comparable to that of electrons, nuclear spins have unique advantages. For instance, they can maintain high entropy even at extremely low temperatures and strong magnetic fields, where electron spin dynamics are inevitably frozen out. Despite these fascinating properties, the application of nuclear spins in spintronics has been limited. Recently, however, spin-current generation from nuclear spins have been reported [1, 2]. These studies utilize an antiferromagnetic insulator $MnCO_3$, in which nuclear and electron spins are coupled by strong hyperfine interaction between them, showing the potential to harness hyperfine coupling for exploring nuclear spintronic phenomena. In this talk, I will discuss our recent results on current-induced nuclear and electron spin dynamics in a metallic ferromagnet and their electrical detection through hyperfine interactions.

This work has been done in collaboration with J. Numata, T. Makiuchi, E. Saitoh (from University of Tokyo), T. Kubota, T. Seki, K. Takanashi, S. Takahashi (from Tohoku University), and H. Chudo, M. Umeda (from Japan Atomic Energy Agency).

REFERENCES

[1]Y. Shiomi, J. Lustikova, S. Watanabe, et al., *Spin pumping from nuclear spin waves*, Nature Physics **15**, 22–26 (2019).

[2]T. Kikkawa, D. Reitz, H. Ito, et al., *Observation of nuclear-spin seebeck effect*, Nature communications **12**, 4356 (2021).

Imaging the Mechanics of Domain Wall Motion with a Single Spin Quantum Magnetometer

Christian Degen[1,*]

[1]Department of Physics, ETH Zurich, Switzerland

*contact: degenc@ethz.ch

Quantum sensors based on spin defects in diamond, most notably the nitrogen-vacancy (NV) center, have emerged as a new tool for investigating nanoscale magnetism with nanotesla sensitivity and sub-50-nm spatial resolution. Quantum sensors bring some unique features to the table, including non-invasiveness, sensitivity to multiple physical parameters (such as magnetic fields, electric fields or currents), and an absolute quantitative calibration based on natural constants. In this talk, I will discuss a recent experiment aimed at imaging the mechanics of domain wall motion in magnetic racetrack devices. Such devices permit electrical actuation of domain walls using spin-orbit torques. I will show that even small DC currents well below the depinning threshold lead to measurable, sub-nanometer displacements of domain walls. These measurements allow mapping of the pinning potential along the wall. I will also discuss the onset of depinning. Finally, I will give an outlook on the prospects of imaging the motion of depinned domain walls for large drive.

Magnetic Imaging of Spin Waves and Supercurrents Using Spins in Diamond and Boron Nitride

Toeno Van Der Sar[1,*]

[1]Department of Quantum Nanoscience, Kavli Institute of Nanoscience, TU Delft, The Netherlands

*contact: t.vandersar@tudelft.nl

Spin waves are collective excitations of the spins in magnetic materials. They play an important role in the thermodynamics of magnetic materials and are promising as signal carriers in information devices. In this talk, I will introduce magnetic imaging based on electron spins in diamond and boron nitride [1–3] as a microscopy technique for studying spins and electric currents in materials on the micro-to-nanoscale[4]. I will show how this technique enables imaging spin waves in thin magnetic films, and describe experiments on the interaction of spin waves with currents in normal[5] and superconducting metals[6]. Our results expand the sensing capabilities of spin-based spin-wave imaging and indicate that superconducting metals provide opportunities for realizing tunable spin-wave optical devices.
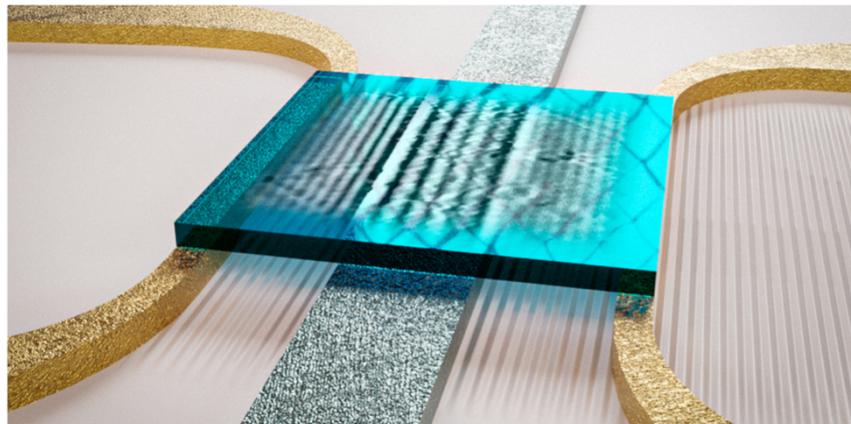
Figure 1: Imaging spin waves underneath a superconducting control electrode using spins in diamond. Credit: M. Borst

REFERENCES

[1]F. Casola, T. van der Sar, and A. Yacoby, *Probing condensed matter physics with magnetometry based on nitrogen-vacancy centres in diamond*, Nature Reviews Materials **3**, 10.1038/natrevmats.2017.88 (2018).

[2]I. Bertelli, J. J. Carmiggelt, T. Yu, et al., *Magnetic resonance imaging of spin-wave transport and interference in a magnetic insulator*, Science Advances **6**, 10.1126/sciadv.abd3556 (2020).

[3]S. Mañas-Valero, Y. C. Doedes, A. Bondarenko, et al., *Isofrequency spin-wave imaging using color center magnetometry for magnon spintronics*, arXiv:2508.18775 (2025).

[4]B. G. Simon, S. Kurdi, J. J. Carmiggelt, et al., *Filtering and imaging of frequency-degenerate spin waves using nanopositioning of a single-spin sensor*, Nano Letters **22**, 9198–9204 (2022).

[5]I. Bertelli, B. G. Simon, T. Yu, et al., *Imaging spin-wave damping underneath metals using electron spins in diamond*, Advanced Quantum Technologies **4**, 10.1002/qute.202100094 (2021).

[6]M. Borst, P. H. Vree, A. Lowther, et al., *Observation and control of hybrid spin-wave–meissner-current transport modes*, Science **382**, 430–434 (2023).

Spin Waves Confined in Microstructures Investigated with a Scanning NV Center Microscope

Aurore Finco[1,*]

[1]Laboratoire Charles Coulomb, CNRS and University of Montpellier, Montpellier, France

*contact: aurore.finco@umontpellier.fr

Scanning NV center microscopy is a versatile technique allowing both the mapping of static magnetic textures [1, 2] and of microwave fields, which can be generated for example by spin waves. Here I will focus on microstructured in-plane ferromagnets, hosting either a S state or a vortex, and show that we can investigate at the same time their magnetization – by tracking the Zeeman shift of the electronic spin resonance frequency of the NV center – and different spin wave modes with frequencies in the vicinity of 2.87 GHz – by measuring the contrast of the NV resonances –, owing to the sensitivity of the NV center to the circular polarization of the field which they produce.
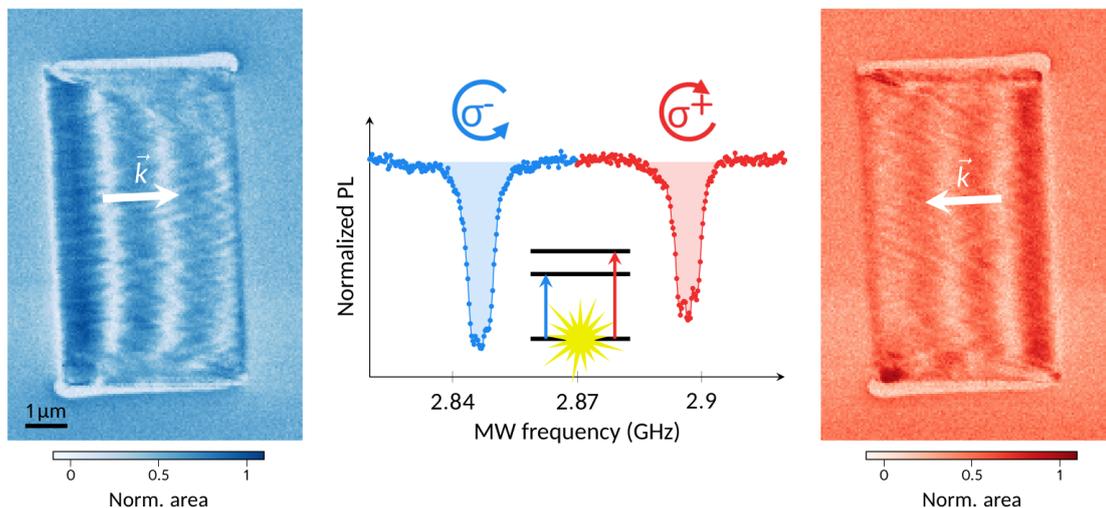
Figure 1: Maps of propagating spin waves in a rectangle of permalloy, measured simultaneously using the two magnetic resonance frequencies of the NV center and highlighting their sensitivity to microwave fields with different circular polarizations.

REFERENCES

[1]A. Finco and V. Jacques, *Single spin magnetometry and relaxometry applied to antiferromagnetic materials*, APL Materials **11**, 100901 (2023).

[2]E. Sfeir, C. Schrader, F. Fabre, et al., *Room temperature magnetic vortices in the van der Waals magnet Fe_5GeTe_2*, Physical Review Materials **9**, 114003 (2025).

Chimeras in Ferroelectrics

Gerrit E.W. Bauer[1,*]

[1]AIMR, Tohoku University, Japan

*contact: bauer.gerrit.ernst.wilhelm.d8@tohoku.ac.jp

The duality between electric and magnetic dipoles in electromagnetism only partly applies to condensed matter. This becomes evident when inspecting the elementary excitations of the magnetic and ferroelectric orders, viz. spin and polarization waves that are quantized into magnons and ferrons, respectively. Magnons are transverse Goldstone modes at GHz frequencies that carry magnetic dipoles, while ferrons (in displacive ferroelectrics) are longitudinal Higgs modes at THz frequencies that carry electric dipoles. The ferrons and magnons received asymmetric attention from the condensed matter community in the past [1] While magnonics is an established and flourishing subfield in magnetism at the brink of contributing to quantum information, ferronics is still non-existent though efforts are on the way to attract the interest of the condensed matter physics community [2]. The ferron concept has stimulated new experiments that extend techniques developed to study the GHz magnetization dynamics to ferroelectric films in the THz regime [3–6], providing evidence of ferron contributions to thermal, optical, and non-local transport properties. Chirality of the optical phonons in uniaxial ferroelectrics may lead to "multiferrons" with unique functionalities [7, 8].

After an introduction into the current state of magnonics and ferronics, I will discuss many open issues of ferron physics.

REFERENCES

[1]G. Bauer, P. Tang, R. Iguchi, et al., *Polarization transport in ferroelectrics*, Physical Review Applied **20**, 10.1103/physrevapplied.20.050501 (2023).

[2]*Spice workshop on "ferrons and magnons: friends or foes?"*, (2026).

[3]B. L. Wooten, R. Iguchi, P. Tang, et al., *Electric field–dependent phonon spectrum and heat conduction in ferroelectrics*, Science Advances **9**, 10.1126/sciadv.add7194 (2023).

[4]J. Choe, T. Handa, C.-Y. Huang, et al., *Observation of coherent ferrons*, 2025.

[5]K. Shen, P. Tang, X. Chen, et al., *Observation of ferron transport in ferroelectrics*, 2025.

[6]B. Zhang, R. Duan, S. S. Mishra, et al., *Electric-field control of giant ferronics*, 2025.

[7]M. Pols, C. P. Romao, and D. M. Juraschek, *Multiferrons: lattice excitations with finite polarization and magnetization*, 2025.

[8]P. Tang and G. E. W. Bauer, *Multiferroic-like quasiparticles in ferroelectrics*, 2025.

Quantum Magnonics in Magnon-Qubit Architecture

Yaroslav M. Blanter[1,*]

[1]Kavli Institute of Nanoscience, Delft University of Technology, Lorentzweg 1, 2628 CJ Delft, The Netherlands
*contact: y.m.blanter@tudelft.nl

A common way to manipulate spin waves (or magnons, their quanta) is by electromagnetic radiation – optical and microwave light. To explore quantum properties of magnons one needs to ensure that they can be reliably created, manipulated, and read out. Until recently, the only proposed and realized quantum readout was to use coupling of a magnon to a superconducting qubit via a microwave cavity. In this talk, I will discuss an alternative proposal — how direct interaction can be induced between a magnet and a qubit and how it can be efficiently used to create non-trivial quantum magnon states [1–3]. I will also show how Heitler effect can be used to create magnons with effectively zero linewidth [4]. In the very last part of the talk, I will briefly talk about the effect of strain on magnetization in various (classical and quantum) situations.

REFERENCES

[1]M. Kounalakis, G. E. W. Bauer, and Y. M. Blanter, *Analog quantum control of magnonic cat states on a chip by a superconducting qubit*, Phys. Rev. Lett. **129**, 037205 (2022).

[2]M. Kounalakis, S. Viola Kusminskiy, and Y. M. Blanter, *Engineering entangled coherent states of magnons and phonons via a transmon qubit*, Phys. Rev. B **108**, 224416 (2023).

[3]M. Dols, S. Sharma, L. Bechara, et al., *Magnon-mediated quantum gates for superconducting qubits*, Phys. Rev. B **110**, 104416 (2024).

[4]E. Ilbuğa, V. V. Dobrovitski, and Y. M. Blanter, *Heitler effect and resonance fluorescence in quantum magnonics*, 2025.

Spin-Orbit Interaction in Azimuthal Spin Waves

T. Valet[1,5,*], **K. Yamamoto**[1,2], **B. Pigeau**[3], **G. De Loubens**[4], **O. Klein**[1]

[1]Université Grenoble Alpes, Cea, Cnrs, Grenoble Inp, Spintec, France
[2]Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Ibaraki, Japan
[3]Université Grenoble Alpes, Cnrs, Grenoble Inp, Institut Néel, France
[4]Spec, Cea, Cnrs, Université Paris-Saclay, Gif-Sur-Yvette, France
[5]Mphysx Oü, Harju Maakond, Tallinn, Lasnamäe Linnaosa, Sepapaja Tn 6, 15551, Estonia

*contact: tvalet@mphysx.com

The angular momentum (AM) carried by wave fields—including spin and orbital components associated with polarization and phase winding—is a central concept across optics, acoustics and condensed matter [1]. In magnonics, however, the orbital AM (OAM) of azimuthal spin-waves has remained difficult to resolve.
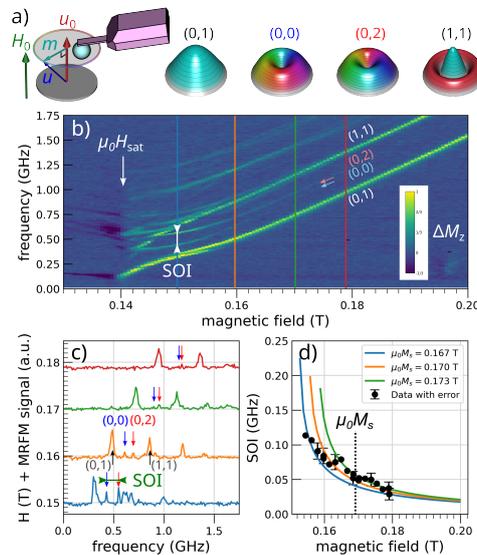
Figure 1: MRFM spectrum near saturation: the split between $(n_R, n_J) = (0,0)$ and $(0,2)$ counter-rotating azimuthal modes reads out magnon OAM via dipolar-induced spin–orbit interaction.

We report a spectroscopic readout of magnon OAM in a normally magnetized yttrium iron garnet (YIG) microdisk using magnetic resonance force microscopy [2]. In the fully saturated state we resolve a frequency splitting between two azimuthal eigenmodes with counter-rotating wavefronts, giving direct access to the sign of the OAM and avoiding the formation of azimuthal standing waves (Fig. 1). The splitting increases when approaching saturation and can exceed the linewidth, enabling a robust frequency-domain readout of OAM states.

The splitting is a magnetic-field tunable magnon spin–orbit interaction induced by the dynamical dipole–dipole interaction. A general AM (spin + orbital) formulation for spin-waves in axisymmetric geometries [3] enables an unambiguous mode assignment and yields quantitative agreement with the field dependence. Beyond this disk geometry, the same spectroscopic principle provides a route to OAM-resolved magnonics and to transduction in hybrid magnon–photon or magnon–phonon platforms.

REFERENCES

[1]K. Y. Bliokh, A. Y. Bekshaev, and F. Nori, *The angular momentum of light*, Physics Reports **592**, 1–38 (2015).

[2]T. Valet, K. Yamamoto, B. Pigeau, G. de Loubens, and O. Klein, *The orbital angular momentum of azimuthal spin-waves*, 2025, arXiv:2503.06556 [cond-mat.mes-hall].

[3]T. Valet, K. Yamamoto, B. Pigeau, G. de Loubens, and O. Klein, *Field theory of linear spin waves in finite textured ferromagnets*, Phys. Rev. B, 10.1103/qyr8-9817 (2025).

Quantum Sensing Magnons Using a Phonon as the Probe

Akashdeep Kamra[1,*]

[1]Department of Physics and State Research Center OPTIMAS, Rheinland-Pfälzische Technische
Universität Kaiserslautern-Landau, 67663 Kaiserslautern, Germany
*contact: akashdeep.kamra@rptu.de

Resolving individual quanta that form a superposition of number states and constitute a general bosonic mode state can be accomplished via a dispersive coupling between the boson and a qubit. This principle has been successfully exploited for resolving microwave photon number states in superconducting circuits [1]. An analogous sensing of magnon quanta in a macroscopic ferromagnet has also been demonstrated employing the same superconducting qubit in a more elaborate setup [2].

Here, we theoretically demonstrate that a seemingly classical bosonic mode can be utilized as a probe for sensing the number states of a magnon mode (see Fig. 1), while outperforming a qubit in various regards as the sensor [3]. Considering another magnon mode in an antiferromagnet as the probe mode, we delineate the required dispersive coupling emerging directly from antiferromagnetic exchange interaction. When a phonon is used as the probe mode, we derive the effective dispersive coupling emerging from the lowest-order nonlinear magnon-phonon interactions. Our two considered examples provide the general design principles for identifying and utilizing a bosonic probe mode for sensing the number state composition in a physical platform of interest.

In the second part, we will discuss an experimental realization of magnon-polarons, the quasiparticles formed from resonant hybridization between a magnon and a phonon, in an acoustic resonator [4]. The intriguing part here is that an acoustic cavity appears to spatially confine the magnonic mode due to magnetoelastic coupling which in turn helps the magnon-phonon hybridization. This interplay of confinement and hybridization is reminiscent of self-hybridized exciton-polaritons [5], and inspires the label self-hybridized magnon-polaron [4].
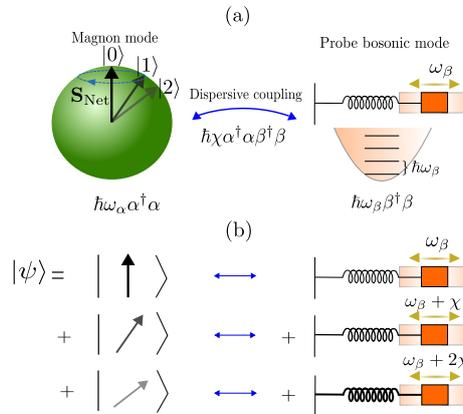

Figure 1: Schematic depiction of the quantum sensing principle and the required dispersive interaction. Figure from Ref. [3]

REFERENCES

[1]D. I. Schuster, A. A. Houck, J. A. Schreier, et al., *Resolving photon number states in a superconducting circuit*, Nature **445**, 515–518 (2007).

[2]D. Lachance-Quirion, Y. Tabuchi, S. Ishino, et al., *Resolving quanta of collective spin excitations in a millimeter-sized ferromagnet*, Science Advances **3**, e1603150 (2017).

[3]B. Dey, S. Verma, M. Weiler, and A. Kamra, *Sensing magnonic quantum superpositions using a bosonic mode as the probe*, arXiv2507.19066 (2025).

[4]K. Künstle, Y. Kunz, T. Moussa, et al., *Magnon-polaron control in a surface magnetoacoustic wave resonator*, arXiv2506.09717 (2025).

[5]F. Dirnberger, J. Quan, R. Bushati, et al., *Magneto-optics in a van der waals magnet tuned by self-hybridized polaritons*, Nature **620**, 533–537 (2023).

All-Electrical Angular Momentum Transport Experiments between Isolated Ferromagnetic Metal Strips

Matthias Althammer[1,*]

[1]Walther-Meißner-Institut, Bavarian Academy of Sciences and Humanities, Germany

*contact: matthias.althammer@wmi.badw.de

Pure spin currents, i.e., the flow of angular momentum without an accompanying charge current, represent a new paradigm in spintronics. Here, I present our recent progress in probing angular momentum transport via all-electrical measurements in isolated metallic ferromagnet strips [1].
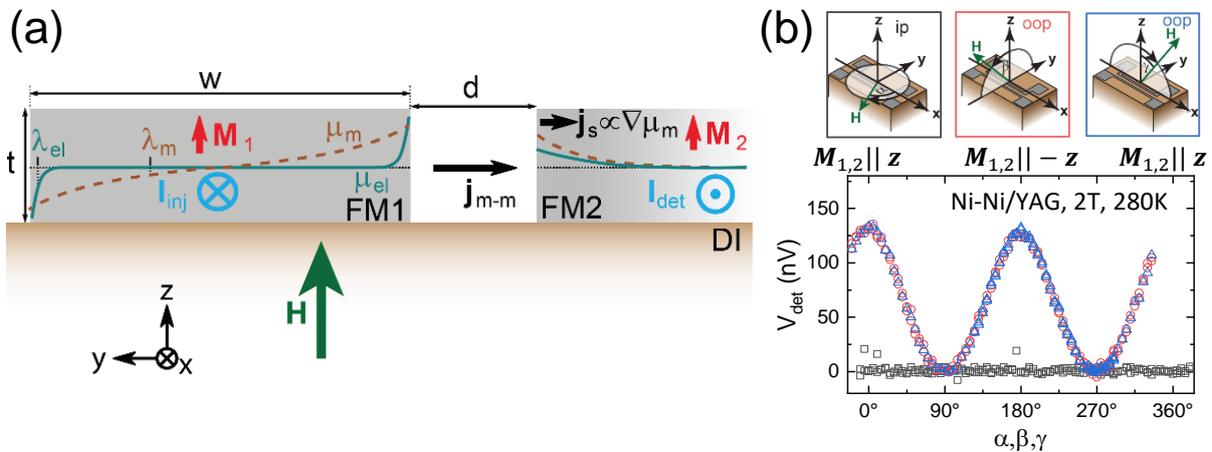
Figure 1: Angular momentum transport in diamagnetic substrates. (a) Illustration of the experimental setup. A charge current in the left FM1 strip induces a magnon accumulation, which in turn induces via angular momentum transport a magnon accumulation in FM2. The magnon accumulation is then transformed into an electronic charge current. (b) Angle-dependent measurements conducted on Ni strips on a single crystalline diamagnetic substrate with an injector current of $100\,\mu\text{A}$. The rotation planes are indicated at the top.

In this talk, I will highlight our recent progress toward separating electronic and magnonic contributions to angular momentum transport in metallic ferromagnets [1]. To this end, we electrically excite and detect spin transport between two parallel and electrically insulated ferromagnetic metal (FM) strips on top of a diamagnetic substrate (see Fig. 1(a)). We observe a finite angular momentum flow to the second ferromagnetic strip across a diamagnetic substrate over micron distances. I illustrate how phononic and dipolar interactions are the likely cause of angular momentum transfer between the two FM strips. Next, I will show how different diamagnetic substrates influence the spin transport signal. I will then discuss our current efforts to separate dipolar and phononic contributions in these transport experiments by using suspended nanostructures. Finally, I will provide an outlook by comparing our results to recent experiments reported by Shen *et al.* [2] on ferron transport in ferroelectric substrates, who employed a similar experimental geometry based on FM strips.

REFERENCES

[1]R. Schlitz, M. Grammer, T. Wimmer, et al., *Electrically induced angular momentum flow between separated ferromagnets*, Phys. Rev. Lett. **132**, 256701 (2024).
[2]K. Shen, P. Tang, X. Chen, et al., *Observation of ferron transport in ferroelectrics*, 2025.

Tunable Complex Magnon-Phonon Coupling in Synthetic Antiferromagnets

Masamitsu Hayashi[1,*]

[1]Department of Physics, The University of Tokyo, Japan

*contact: hayashi@phys.s.u-tokyo.ac.jp

The coupling of quasi-particles in soilds is attracting interest due to their potential applications in quantum technologies. Many studies have focused on the coupling strength, aiming to develop systems with strong and possibly ultrastrong coupling. Simultaneously, it is equally import to clarify the underlying physics of the coupling. We have studied the strength and phase of the complex coupling of magnons and acoustic phonons in magnetic thin film heterostructures.

A surface acoustic wave (SAW) cavity resonator is patterned on a Lithium Niobate substrate. The quality factor of the resonator exceeds 3000 at room temperature. The strength of the magnon-phonon coupling in magnetic thin heterostructures is studied by the change in the SAW spectrum linewidth with magnetic field. We find that the coupling strength is of the order of 10 MHz for heterostructures that contain transition metal ferromagnets. In the presentation, we show that the phase of the coupling can be tuned using magnetic field.
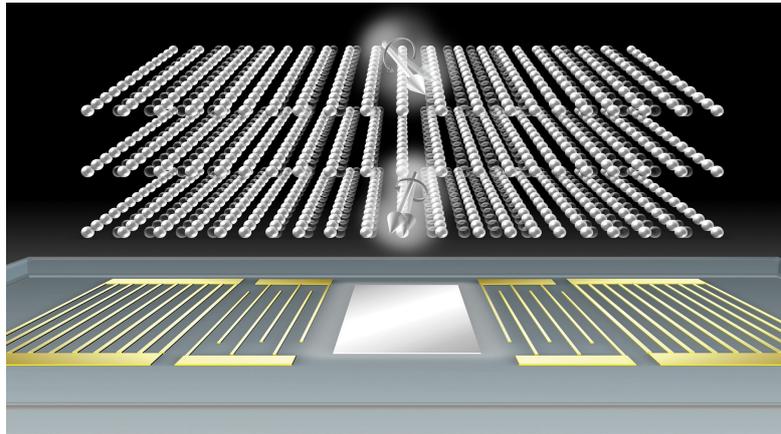
Figure 1: Schematic illustration of magnon-phonon coupling[1].

REFERENCES

[1]H. Matsumoto, I. Yasuda, M. Asano, et al., *Magnon-phonon coupling of synthetic antiferromagnets in a surface acoustic wave cavity resonator*, Nano Lett. **24**, 5683 (2024).

Controlling Magnons and Their Transport by Electronic Spin Injection

Richard Schlitz[1,*]

[1]Universität Konstanz, Konstanz, Germany

*contact: richard.schlitz@uni-konstanz.de

Magnons are quantized excitations of the magnetization texture in ordered magnets, which can be used to transport spin information. In recent years, a new device concept in magnonics has demonstrated that direct-current electrical transport can provide access to the transport properties of magnons. These devices exploit angular momentum conversion from the electrical to the magnonic domain to electrically generate and detect magnon spin currents in heterostructures composed of a magnetic insulator and a heavy metal [1]. Recent studies have shown that in the nonlinear regime the changes in the nonlocal transport allow us also to obtain information on the transported magnon manifold [2, 3].

In this talk, I will show that cavity modes can form in a magnetic insulator region confined between two Pt nanostripes, where interfacial anisotropy modifies the magnon dispersion. These modes hybridize with boundary magnons in the Pt-capped regions, producing a distinct anticrossing gap. Nonlinear spin current injection enables control of the magnon–magnon coupling by altering the cavity boundary conditions, leading to the suppression of the cavity modes beyond the damping compensation threshold [4].

I will further show that entering the nonlinear regime, local modifications of the magnon dispersion can sensitively affect nonlocal magnon transport, giving rise to a strong enhancement of the number of specific low-energy magnons. Considering the role of nonlinear relaxation processes, the nonlocal transport can be reconciled with the local modification of the magnon dispersion. These results suggest that nonlocal transport measurements, despite averaging over all modes, are a sensitive probe to unravel changes to the magnon manifold [5].

These results showcase the rich opportunities that arise when magnons are driven into the nonlinear regime by spin injection.

REFERENCES

[1]L. J. Cornelissen, J. Liu, R. A. Duine, J. Ben Youssef, and B. J. van Wees, *Long-distance transport of magnon spin information in a magnetic insulator at room temperature*, Nature Physics **11**, 1022–1026 (2015).

[2]R. Kohno, K. An, E. Clot, et al., *Nonlocal magnon transconductance in extended magnetic insulating films. I. Spin diode effect*, Physical Review B **108**, 144410 (2023).

[3]R. Kohno, K. An, E. Clot, et al., *Nonlocal magnon transconductance in extended magnetic insulating films. II. Two-fluid behavior*, Physical Review B **108**, 144411 (2023).

[4]H. Wang, W. Legrand, R. Schlitz, and P. Gambardella, *Current-Controlled Magnon–Magnon Coupling in an On-Chip Cavity Resonator*, Nano Letters **25**, 9090–9097 (2025).

[5]R. Schlitz, V. E. Demidov, M. Lammel, S. O. Demokritov, and P. Gambardella, *Auto-oscillations and directional magnon emission induced by spin current injection into large magnetic volumes*, Nature Communications **16**, 8472 (2025).

Spin-Wave Modes and Nonlinear Interactions in Bi:YIG Disks for Magnonic Neural Network Implementation in Reciprocal Space

David Zehner[1], Ping Che[1], Romain Lebrun[1], Dédalo Sanz Hernández[1], Ádám Papp[2], Jamal Ben Youssef[3], Manuel Muñoz[1], Isabella Boventer[1], Vincent Cros[1], Paolo Bortolotti[1], Abdelmadjid Anane[1,*]

[1]Laboratoire Albert Fert, CNRS, Thales, Université Paris-Saclay, Palaiseau, France
[2]Faculty of Information Technology, Pázmány Péter Catholic University, Budapest, Hungary
[3]LabSTICC, CNRS, Université De Bretagne Occidentale, Brest, France
[4]Instituto De Tecnologías Físicas Y De La Información (CSIC), Madrid, Spain

*contact: madjid.anane@université-paris-saclay.fr

Neuromorphic computing based on physical dynamical systems provides a route toward energy-efficient, non-CMOS information processing, but remains limited by training complexity and network depth. We experimentally demonstrate a neuromorphic platform based on nonlinear interactions among a large number of spin-wave eigenmodes in Bi:YIG microdisks. Parametric excitation at twice the eigenmode frequencies generates an intrinsic network in reciprocal space, enabling computation without hardwired neuron–synapse connections and allowing effective all-to-all mode coupling. Pulsed microwave inputs exploit temporal memory and non-reciprocal dynamics, while a trainable linear embedding maps input data onto physical control parameters. A surrogate model enables efficient backpropagation-based training, establishing the system as an interpretable magnonic hardware platform for nonlinear computation. Spin waves are excited parametrically using microwave pulse sequences applied through an on-chip antenna, generating a homogeneous radio-frequency magnetic field oriented at approximately 30° with respect to the static magnetization. The spin-wave response is detected electrically via the same transmission line by filtering out the excitation signal and analyzing the transmitted spectrum. The system is driven by overlapping pulses with controlled amplitude, frequency, phase, duration, and temporal overlap. Time-ordered excitation of distinct modes reveals strong nonlinear effects, including mode-dependent frequency shifts, amplitude suppression, and temporal non-reciprocity. Reversing the excitation order produces asymmetric spectral responses, with output suppression differing by up to 40% between forward and time-reversed sequences, indicating a finite temporal memory extending to approximately 100 ns. The measured response is analyzed through the time-integrated spin-wave spectrum, discretized into frequency bins to quantify nonlinear mode interactions and identify reproducible operating regimes governed by intrinsic spin-wave coupling.
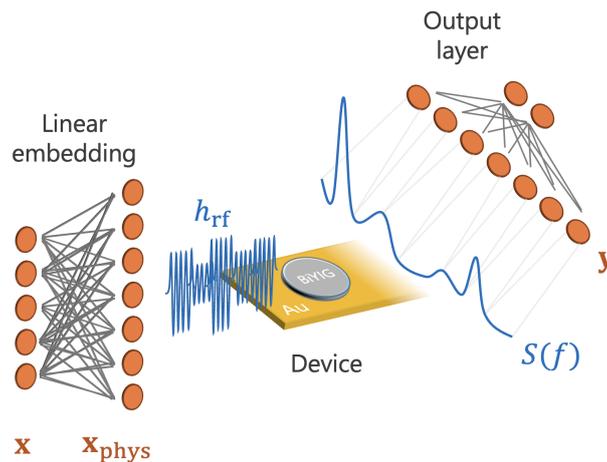
Figure 1: The n-dimensional input vector $\mathbf{x}$ is linearly embedded into physical control parameters $\mathbf{x}_{\mathrm{phys}}$ that define the microwave excitation field. The measured spin-wave spectrum is discretized into frequency bins and mapped to the output through a trainable linear readout.

Real-Space Imaging of Magnons Interacting with Noncollinear Magnetic Textures

Ping Che[1,*]

[1]Laboratoire Albert Fert, CNRS, Thales, Université Paris-Saclay, Palaiseau, France

*contact: ping.che@cnrs-thales.fr

Noncollinear magnetic textures such as skyrmions, bubbles, and domain walls are attracting significant attention in magnonics because they interact with magnons through their internal spin structure, topology, and handedness. These interactions give rise to nontrivial magnon band topology [1], magnon–skyrmion skew scattering [2], multipole magnon modes [3], and edge-localized magnon transport [4], providing new routes to control magnon phase, momentum, and propagation direction. Moreover, such textures can be stabilized without demanding nanofabrication, making them promising building blocks for nanoscale magnonic devices that enable guided and nonreciprocal signal transmission in magnonic circuits. However, experimental verification and real-space imaging of these magnon-noncollinear magnetic textures interactions remain limited. It is challenging to simultaneously realize both low-damping materials that host rich noncollinear magnetic textures at room-temperature, and a microscopy technique capable of resolving both their static configuration and magnon-driven dynamics at the nanoscale.

In this talk, I will present real-space imaging of magnons interacting with magnetic skyrmions, type-II bubbles and domain walls at room temperature using time-resolved scanning transmission x-ray microscope (STXM). In bismuth-dope yttrium iron garnet (Bi-YIG) thin films and Fe/Gd multilayers with interface-induced perpendicular magnetic anisotropy (PMA), the interplay between anisotropy and dipolar energy stabilizes rich magnetic textures including dipolar skyrmions with dimensions of about 200 nm. Time-resolved STXM allows direct visualization of magnon propagation, scattering, and confinement within the textures. We observed that resonantly excited magnons can drive the translational motion of skyrmions and bubbles, reaching a velocity up to 175 m/s. This provides direct experimental evidence that magnons transfer momentum to magnetic textures and move them without electrical current. In addition, we image nonreciprocal magnons confined to deep-sub-100 nm-wide domain walls which is the key to construct chiral edge magnons. These results show that magnons can manipulate noncollinear textures and use them as information transformation channel, enabling energy-efficient and reconfigurable room-temperature magnonic devices.

REFERENCES

[1]T. Weber et al., *Topological magnon band structure of emergent landau levels in a skyrmion lattice*, Science **375**, 1025–1030 (2022).

[2]C. Schütte and M. Garst, *Magnon-skyrmion scattering in chiral magnets*, Phys. Rev. B **90**, 094423 (2014).

[3]P. Che et al., *Short-wave magnons with multipole spin precession detected in the topological bands of a skyrmion lattice*, Commun. Mater. **6**, 139 (2025).

[4]P. Che et al., *Nonreciprocal spin waves in nanoscale hybrid néel–bloch–néel domain walls detected by scanning x-ray microscopy in perpendicular magnetic anisotropic fe/gd multilayers*, Adv. Mater. **37**, e08181 (2025).

Topological and Nonreciprocal Phononics in the Gigahertz Regime

Yoichi Nii[1,*]

[1]Department of Applied Physics and Physico-Informatics, Keio University, Japan

*contact: yoichi.nii@keio.jp

Topological concepts are transforming our ability to manipulate waves with robustness and directionality. In phononics, such ideas promise low-dissipation, disorder-immune wave guiding, enabling new acoustic device functionalities [1]. In the first part of this talk, we introduce our experimental realization of gigahertz topological surface acoustic waves (SAWs) using nanoscale phononic crystals and microwave impedance microscopy [2]. We directly visualize topological edge modes within the bandgap, demonstrating localized phonon guiding at GHz frequencies. These results indicate a new pathway toward integrated phononic circuits, where topological protection could facilitate robust signal routing for both classical and quantum information technologies.

In the second part, we discuss a complementary direction based on nonreciprocal SAW transport mediated by magnetoelastic coupling [3, 4]. We recently observed nonreciprocal diffraction of SAWs [4], arising from the transfer of spin angular momentum to the phonon.

While these two directions -topological and nonreciprocal phononics- have not yet been unified experimentally, they together point toward a promising frontier: combining topological phononic waveguides with magnetic interactions to actively engineer nonreciprocal or chiral phonon transport. Such integration may unlock novel functionalities ranging from on-chip signal routing to hybrid quantum interfaces.
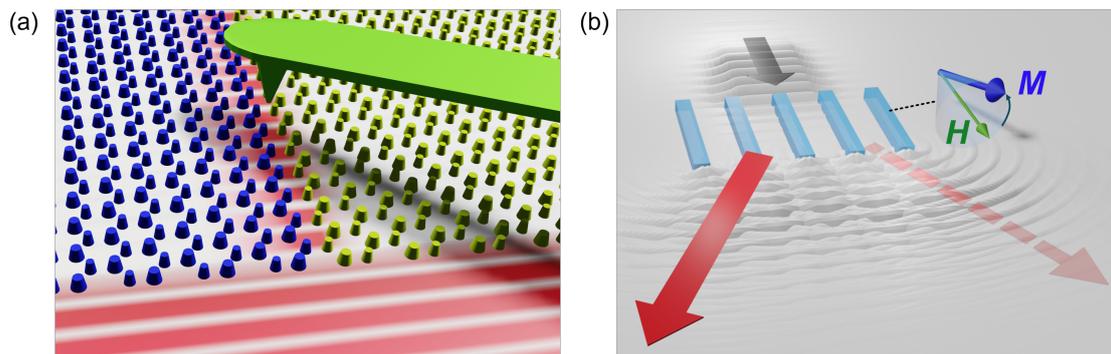

Figure 1: (a) Topological SAW and (b) nonreciprocal diffraction of SAW.

REFERENCES

[1] T. Shah, C. Brendel, V. Peano, and F. Marquardt, *Colloquium: topologically protected transport in engineered mechanical systems*, Rev. Mod. Phys. **96**, 021002 (2024).

[2] Y. Nii and Y. Onose, *Imaging an acoustic topological edge mode on a patterned substrate with microwave impedance microscopy*, Phys. Rev. Appl. **19**, 014001 (2023).

[3] R. Sasaki, Y. Nii, Y. Iguchi, and Y. Onose, *Nonreciprocal propagation of surface acoustic wave in* $Ni/LiNbO_3$, Phys. Rev. B **95**, 020407 (2017).

[4] Y. Nii, K. Yamamoto, M. Kanno, S. Maekawa, and Y. Onose, *Observation of nonreciprocal diffraction of surface acoustic wave*, Phys. Rev. Lett. **134**, 027001 (2025).

Decoherence Spectroscopy of Spin Waves in Van Der Waals Antiferromagnets

Debarghya Dutta[1,*]**, Clément Pellet-Mary**[1]**, Patrick Maletinsky**[1]

[1]Department of Physics, University of Basel, Basel, Switzerland

*contact: debarghya.dutta@unibas.ch

The advent of two-dimensional magnetic van der Waals (vdW) materials have expanded the boundaries of nano-magnetism and led to novel ideas for information transfer in the field of spintronics [1]. By probing the intrinsic layer-dependent magnetic phases, it is possible to gain insight into the spin structure and dynamics [2]. We are interested in CrSBr, a layered anti-ferromagnet with intralayer ferromagnetic (FM) and interlayer anti-ferromagnetic (AFM) coupling [3]. Using our cryogenic scanning Nitrogen-vacancy (NV) magnetometer [4], we demonstrate a novel method of lateral exchange bias (LEB) to control the Neél vector, which is the primary order parameter in antiferromagnets. Using this technique, we are able to engineer different orientations of the Neél vector to controllably write domain walls (DWs) in the AFM bilayer [5] as demonstrated in Figure. 1.

Furthermore, by using NV-based decoherence spectroscopy, we show the presence of spin waves localized at the domain wall. In particular, we observe that the NV spin exhibits increased decoherence as it approaches the DW. Our measurements provide direct insight to the dynamical degrees of freedom associated to the DW motion, and ultimately towards controlled driving of the DW motion in two-dimensional antiferromagnets.
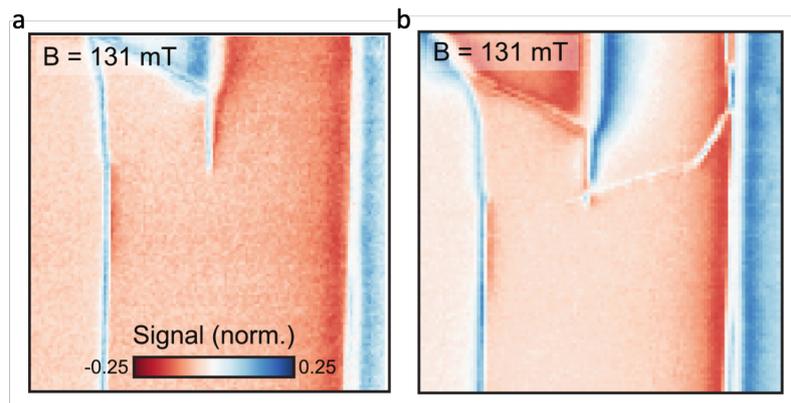

Figure 1: Controlled Writing of Domain Wall in AFM Bilayer CrSBr
By reversing the direction of magnetization in the control layer (3-Layer) with respect to the pinning layer (7-layer), we can imprint antiferromagnetic domain walls into the bilayer. **a.** No Domain Wall (DW) since the control and pinning layer are oriented in the same direction. **b.** Control and pinning layer are oriented in opposite directions, leading to the appearance of a DW via lateral exchange bias (LEB).

REFERENCES

[1]A. V. Chumak, V. I. Vasyuchka, A. A. Serga, and B. Hillebrands, *Magnon spintronics*, Nature Physics **11**, 453–461 (2015).

[2]M. Gibertini, M. Koperski, A. F. Morpurgo, and K. S. Novoselov, *Magnetic 2d materials and heterostructures*, Nature Nanotechnology **14**, 408–419 (2019).

[3]S. A. López-Paz, Z. Guguchia, V. Y. Pomjakushin, et al., *Dynamic magnetic crossover at the origin of the hidden-order in van der waals antiferromagnet crsbr*, Nature Communications **13**, 10.1038/s41467-022-32290-4 (2022).

[4]M. A. Tschudin, D. A. Broadway, P. Siegwolf, et al., *Imaging nanomagnetism and magnetic phase transitions in atomically thin crsbr*, Nature Communications **15**, 10.1038/s41467-024-49717-9 (2024).

[5]C. Pellet-Mary, D. Dutta, M. A. Tschudin, et al., *Lateral exchange bias for néel-vector control in atomically thin antiferromagnets*, Nature Communications **16**, 10.1038/s41467-025-64700-8 (2025).

Steady-State Entanglement of Spin Qubits Mediated by Non-Reciprocal and Chiral Magnons

Martijn Dols[1,*], Mikhail Cherkasskii[1], Victor A. S. V. Bittencourt[2], Carlos Gonzalez-Ballestero[3], Durga B.R. Dasari[4], Silvia Viola Kusminskiy[1,5]

[1]Institute for Theoretical Solid State Physics, RWTH Aachen University, Germany
[2]Institut De Science Et D'Ingénierie Supramoléculaires (ISIS), Université De Strasbourg, France
[3]Institute for Theoretical Physics and Vienna Center for Quantum Science and Technology, TU Wien, Austria
[4]3. Physikalisches Institut, ZAQuant, University of Stuttgart, Germany
[5]Max Planck Institute for the Science of Light, Germany

*contact: martijn.dols@rwth-aachen.de

We propose a hybrid quantum system in which a magnet supporting non-reciprocal magnons, chiral magnons, or both mediates the dissipative and unidirectional coupling of spin qubits. By driving the qubits, the steady state of this qubit-qubit coupling scheme becomes the maximally entangled Bell state. We devise a protocol where the system converges to this entangled state and benchmark it including qubit decay and dephasing. The protocol is numerically tested on a hybrid system consisting of nitrogen-vacancy (NV) centers coupled to magnon surface modes of an yttrium iron garnet (YIG) film. We show that the dephasing time of the NV centers forms the bottleneck for achieving the entanglement of NV centers separated by a distance exceeding microns. Our findings identify the key technological requirements and demonstrate a viable route toward steadystate entanglement of solid-state spins over distances of several microns using magnonic quantum networks, expanding the toolbox of magnonics for quantum information purposes.

Magnon Kerr Effect in a Ferrimagnetic Thin Film

Davit Petrosyan[1,*], **Hiroki Matsumoto**[1,2], **Hanchen Wang**[1], **Jamal Ben Youssef**[3], **Richard Schlitz**[4], **William Legrand**[1,5], **Pietro Gambardella**[1]

[1]Department of Materials, ETH Zurich, CH-8093 Zurich, Switzerland
[2]Institute of Chemical Research, Kyoto University, 6110011 Uji, Japan
[3]LabSTICC, CNRS, Université De Bretagne Occidentale, 29238 Brest, France
[4]Department of Physics, University of Konstanz, 78457 Konstanz, Germany
[5]Université Grenoble Alpes, CNRS, Institut Néel, 38042 Grenoble, France

*contact: davit.petrosyan@mat.ethz.ch

Cavity magnonics studies the coherent interaction between magnons and microwave photons, providing a platform to explore light–matter interaction in magnetic materials [1]. Driving the system into the nonlinear regime unlocks new magnonic phenomena, such as power-dependent frequency shifts [2], bistability of magnons [3], and entanglement between magnons and other bosons [4]. Among magnon nonlinearities, the magnon Kerr effect (MKE) appears universally in any ferromagnetic system with finite anisotropy and manifests itself as a self-induced frequency shift of the magnon modes. We have studied the MKE using a high-quality 200-nm thick yttrium iron garnet film, grown by liquid phase epitaxy, in a strongly coupled cavity–magnon system [5]. The cavity is of the loop-gap type, optimized to couple with thin films of magnetic insulators [6]. The strong coupling in the system is characterized by the avoided crossing in Fig. 1(a). The MKE is probed as frequency shifts of the magnon–polariton branches when increasing the microwave power [Fig. 1(b)], and the cavity serves as a sensitive probe of the magnon dynamics. We investigate the MKE for all angles of the magnetization with respect to the film plane. The experimental data is well described by a newly derived theoretical model of the MKE in a thin ferromagnetic film [7]. Our study predicts the trade-off between anharmonicity of a magnonic system and the threshold for coherent magnon–photon coupling, which is necessary for probing the magnetization dynamics.
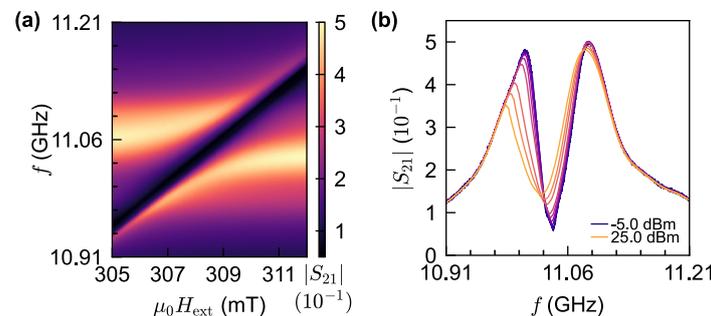

Figure 1: **(a)** Field- and frequency-dependent microwave transmission of the coupled magnon–photon system featuring the avoided crossing, measured in the in-plane configuration at $-5\,\mathrm{dBm}$. **(b)** Power- and frequency-dependent microwave transmission measurements of the coupled magnon-photon system at a fixed field near the center of the avoided crossing.

REFERENCES

[1]B. Zare Rameshti, S. Viola Kusminskiy, J. A. Haigh, et al., *Cavity magnonics*, Phys. Rep. **979**, 1–61 (2022).

[2]Y.-P. Wang, G.-Q. Zhang, D. Zhang, et al., *Magnon Kerr effect in a strongly coupled cavity-magnon system*, Phys. Rev. B **94**, 224410 (2016).

[3]Y.-P. Wang, G.-Q. Zhang, D. Zhang, et al., *Bistability of cavity magnon polaritons*, Phys. Rev. Lett. **120**, 057202 (2018).

[4]R.-C. Shen, J. Li, Z.-Y. Fan, Y.-P. Wang, and J. Q. You, *Mechanical bistability in Kerr-modified cavity magnomechanics*, Phys. Rev. Lett. **129**, 123601 (2022).

[5]D. Petrosyan, H. Matsumoto, H. Wang, et al., *Magnon Kerr effect in a ferrimagnetic thin film*, in preparation.

[6]F. Zanichelli, D. Petrosyan, H. Wang, et al., *Loop-gap resonators achieving strong magnon–photon coupling in magnetic insulator thin films*, in review.

[7]D. Petrosyan, H. Matsumoto, H. Wang, et al., *Model of the magnon Kerr effect in a highly anisotropic ferromagnet*, in preparation.

Posters

Classical and Quantum Theory of Magnonic and Magnetoelastic Nonlinear Dynamics in Continuum Geometries

Marco Brühlmann[1,*]**, Yunyoung Hwang**[2,3]**, Jorge Puebla**[2,4]**, Carlos Gonzalez-Ballestero**[1]

[1]Institute for Theoretical Physics and Vienna Center for Quantum Science and Technology, Vienna University of Technology, Austria
[2]CEMS, RIKEN, Japan
[3]Institute for Solid State Physics, University of Tokyo, Japan
[4]Department of Electronic Science and Engineering, Kyoto University, Japan

*contact: marco.bruehlmann@tuwien.ac.at

Magnons, collective quantum excitations of spin ensembles in a ferromagnet, couple to a number of different degrees of freedom, e.g. phonons. The exceptional tunability of magnonic and phononic systems has allowed the experimental realization of strong magnetoelastic coupling [1, 2] in systems consisting of a thin ferrimagnetic film on a non-magnetizable substrate (see Fig. 1). Recently, the parametric drive of magnons through strongly driven phonons has resulted in the observation of subharmonic excitations in the magnon spectrum [1, 3]. The appearance of these subharmonic excitations bears strong similarities with spontaneous parametric down-conversion (SPDC) observed in photonic systems. Similarly to SPDC, which allows the generation of entangled photon pairs , the present magnonic and magnetoelastic processes can also be used to generate entanglement between magnons. Investigating entanglement necessitates a quantum theory. Furthermore, quantum modeling and optimization of entangled states would benefit greatly from an analytical model describing the generation of parametric magnon instabilities.

We present the findings of our work[1] [4] in which we formulate a fully analytical classical theory which lets us Identify multiple competing nonlinear interaction processes that contribute to the emergence of subharmonic magnetization spectrum peaks. It also lets us understand what modes are excited by the parametric instabilities and why certain modes are suppressed and predict quantitatively the threshold values of the driving power at which specific magnon modes are parametrically amplified by the spontaneous nonlinear scattering processes. This formalism has successfully reproduced quantitative experimental results [1]. We have extended this theory into the quantum regime and are exploring the possibilities of entangled state generation.
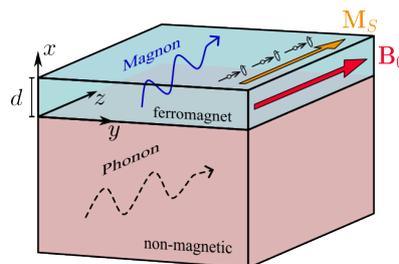

Figure 1: In-plane propagating magnons in a ferromagnetic thin film couple strongly and nonlinearly to SAW phonons.

REFERENCES

[1]Y. Hwang, L. Liao, J. Puebla, et al., *Harmonic and subharmonic magnon generation in a surface acoustic wave resonator*, 2025.

[2]C. Berk, M. Jaris, W. Yang, et al., *Strongly coupled magnon–phonon dynamics in a single nanomagnet*, Nature Communications **10**, 10.1038/s41467-019-10545-x (2019).

[3]M. Geilen, R. Verba, A. Hamadeh, et al., *Parametric excitation and instabilities of spin waves driven by surface acoustic waves*, Advanced Physics Research **4**, 10.1002/apxr.202400086 (2024).

[4]M. Brühlmann, Y. Hwang, J. Puebla, and C. Gonzalez-Ballestero, *Classical and quantum theory of magnonic and magnetoelastic nonlinear dynamics in continuum geometries*, 2025.

Coupling the Orbital Angular Momentum of Elastic Waves with the Gyromotion of a Magnetic Vortex

G. Olivetti[1,*], B. Pigeau[1], K. Yamamoto[2], T. Valet[1], Y. Otani[3], O. Klein[1]

[1]Université Grenoble Alpes, CEA, Spintec; Université Grenoble Alpes, CNRS, Institut Néel, Grenoble, France
[2]Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Japan
[3]Institute for Solid State Physics, The University of Tokyo, Kashiwa, Chiba 277-8581, Japan

*contact: giovanni.olivetti@neel.cnrs.fr

Recent studies on magneto-elasticity have demonstrated long-range coherent coupling between distant macrospins via the transfer of the spin angular momentum (SAM) component of magnetization dynamics into chiral phonons [1]. These findings have drawn increasing interdisciplinary interest in the mechanisms of angular momentum transfer between distinct systems, but the orbital angular momentum (OAM) counterpart [2] remains experimentally unexplored.

In this work, we report on the design of an experiment to spectroscopically excite and detect non-vanishing OAM in an axisymmetric magnetic nanostructure. Our approach focuses on the coupling between the fundamental mode of a magnetic vortex texture—the gyromotion of the vortex core—and an elastic wave carrying OAM (see Fig. 1). Such a rotating elastic wave has been generated in the $\sim$100 MHz regime via spiral-shaped interdigital transducers on X-cut LiNbO$_3$ substrate, and characterized using time-resolved Michelson interferometry[3]. A magnetic vortex ground state is stabilized in Permalloy disks of variable radius, whose gyrotropic mode is characterized using time-resolved MOKE microscopy and identified in the $\sim$100 MHz frequency range.

Reversal of the vortex core polarity enables control of the relative handedness between vortex gyration and acoustic OAM, allowing investigation of how angular momentum sign influences the coupling efficiency. This work provides a platform to explore the transfer of orbital angular momentum between elastic excitations and magnetic textures, opening routes toward controlled hybrid magnon–phonon systems.
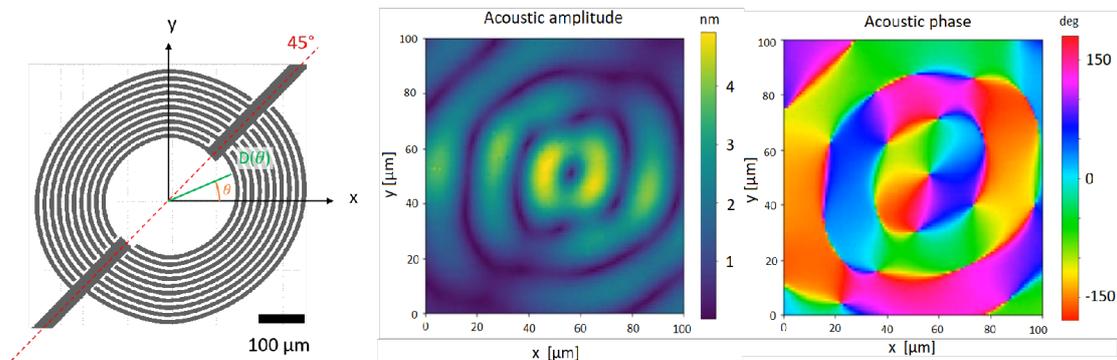

Figure 1: Left: Design of the interdigitated transducer (IDT) used to generate acoustic waves carrying orbital angular momentum; the electrode geometry follows a spiral phase profile. Right: Experimentally measured spatial maps of the vertical surface displacement amplitude (center) and phase (right) of the acoustic field, confirming the generation of a chiral wavefront with non-zero orbital angular momentum.

REFERENCES

[1]K. An and A. N. Litvinenko, Phys. Rev. B **101**, 060407 (2020).
[2]D. A. Garanin, Phys. Rev. B **92**, 024421 (2015).
[3]Z. Tian, Science Advances **6**, eabb0494 (2020).

Enhanced Synchronization in Coupled Oscillators Induced by Dissipative Coupling

Jiang Xiao[1,*], **Jiongjie Wang**[1,2], **Xiangshan Zeng**[2]

[1]Department of Physics, Fudan University, Shanghai, China

*contact: xiaojiang@fudan.edu.cn

Since the pioneering observations of Christiaan Huygens in the seventeenth century, the phenomenon of synchronization between two self-sustained oscillators—such as coupled pendulum clocks—has remained a fundamental topic in nonlinear dynamics. It is well established that when the coupling strength between two oscillators exceeds the frequency detuning, phase and frequency locking can occur, leading to a synchronized state.

In recent years, related phenomena have been explored in many hybrid systems (such as magnon-cavity system) characterized by non-Hermitian Hamiltonians, where dissipative coupling between modes gives rise to mode coalescence and exceptional points.

In this theoretical investigation, we explore the interplay between non-linear and non-Hermitian physics to examine how dissipative coupling influences the robustness and conditions of synchronization between two self-sustained oscillators. Our analysis demonstrates that as the coupling character shifts from coherent to dissipative, the synchronization range with respect to frequency detuning expands markedly (see Figure below). Moreover, we identify two distinct synchronization regimes associated with dissipative interaction. The first regime, referred to as *balanced synchronization*, corresponds to the conventional case in which both oscillators attain similar amplitudes and share a unified frequency once synchronized. The second regime, termed *imbalanced synchronization*, arises when one oscillation mode is effectively suppressed, leaving the system to oscillate collectively through a single dominant mode. Although this imbalanced state displays asymmetric amplitudes and may represent a less ideal form of synchronization, it notably extends the overall range of achievable synchronization.
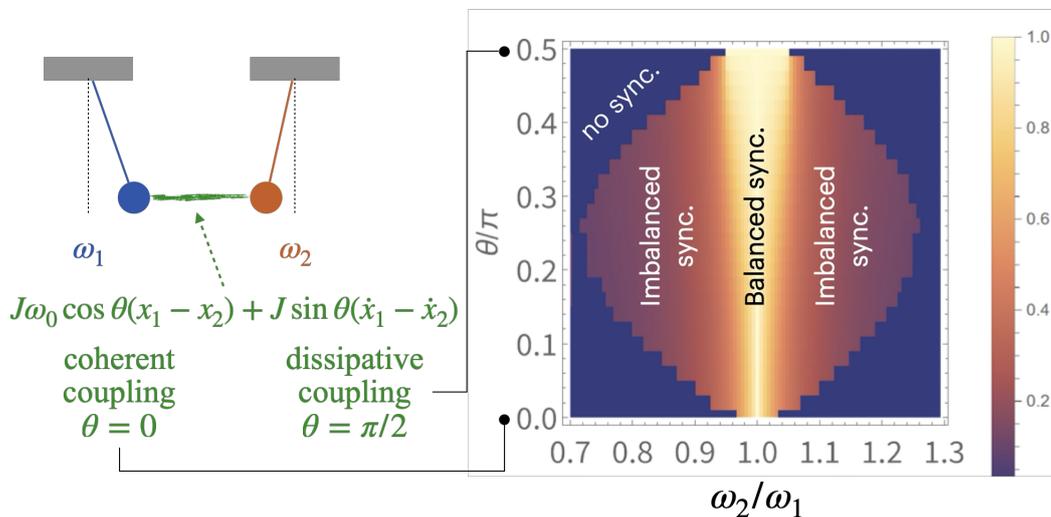

Figure 1: Left: two (self-sustained) oscillators coupled via a hybrid coherent and dissipative coupling parametrized by coupling phase θ. Right: The simulated synchronization phase diagram as function of ω_2/ω_1 and coupling phase θ.

Overall, our analysis demonstrates that dissipative coupling not only enhances the occurrence of synchronization but also introduces an additional, qualitatively different mechanism underpinning it. These insights enrich our understanding of nonlinear dynamics in non-Hermitian systems and open up new avenues for exploring synchronization phenomena in a broader class of physical and engineered systems.

Generation of Chaotic Signals with Vortex Based Spin-Torque Nano-Oscillators

Léna Le Roux - Kadhi[1,*]**, Pacôme Colin**[2]**, Abderrazak Hakam**[1]**, Chloé Chopin**[1]**, Slavisa Jovanovic**[3]**, Sébastien Petit-Watelot**[2]**, Philippe Talatchian**[1]**, Damien Rontani**[3]**, Ursula Ebels**[1]

[1]Spintec, Université Grenoble Alpes, CEA, CNRS, Grenoble INP-UGA, Grenoble, France
[2]Institut Jean-Lamour, CNRS, Université De Lorraine, Nancy, France
[3]LMOPS EA 4423 Laboratory, Centrale Supélec, Université De Lorraine, Metz, France

*contact: lenak.le.roux@gmail.com

Encryption of data and communication protocols is a key requirement for secure access to data as well as secure communication of information within wireless sensor networks and communicating objects. For this, encryption keys are used that are based on random numbers. However, when generated by conventional digital hardware, the generated numbers are only pseudo-random. Therefore, in order to generate true random numbers, it is preferable to exploit physical processes such as quantum fluctuations, thermal noise [1] or chaotic signals.

In this presentation we will explore experimentally the non-linear dynamic properties of the auto-oscillations of spin-torque nano-oscillators to generate chaotic signals that can then be employed for true random number generation. While numerous numerical studies can be found in the literature, experimental implementations are limited [2] [3] [4] [5].

To access experimentally a chaotic dynamic, several conditions must be fulfilled: the system must be strongly non-linear and it must possess a sufficiently large number of degrees of freedom (Poincaré-Bendixon theorem). Coupling several subsystems, injecting a non-linear driving force or use time-delayed feedback techniques could enhance the non linearity of a system. These mechanism also raise the dimension of the phase space since new state variables or delayed terms act as additional degrees of freedom.

Here we will present preliminary experimental results on the delayed feedback technique, where the output signal of a vortex state spin torque nano-oscillator is fed into a field line antenna placed on top of the STVO, which generates a local rf magnetic field, and through this acts on the dynamic state of the vortex auto-oscillation [6] [7]. We will present a detailed analysis on the influence of the feedback parameters: strength and phase. When increasing the feedback signal amplitude, a transition of a well-defined single oscillation peak to a frequency comb is observed. The dynamics properties such as the Lyapunov exponent and the fractal dimension are extracted from a reconstructed attractors in the phase space from voltage time series and completed by noise titration analysis.

This analysis confirms that under specific values of the feedback parameters a chaotic dynamic state can be reached. These methods will be extended to other schemes to generate chaotic signals. Furthermore, conditioning of the chaotic signal to generate a true random bitstream from the chaotic signal will be discussed.

REFERENCES

[1]N.-T. Phan, N. Prasad, A. Hakam, et al., *Unbiased random bitstream generation using injection-locked spin-torque nano-oscillators*, Physical Review Applied **21**, 034063 (2024).

[2]S. Petit-Watelot, J.-V. Kim, A. Ruotolo, et al., *Commensurability and chaos in magnetic vortex oscillations*, Nature Physics **8**, 682–687 (2012).

[3]A. V. Bondarenko, E. Holmgren, Z.-W. Li, B. A. Ivanov, and V. Korenivski, *Chaotic dynamics in spin-vortex pairs*, Physical Review B **99**, 054402 (2019).

[4]E. A. Montoya, P. A. Omelchenko, C. Coutts, I. N. Krivorotov, et al., *Magnetization reversal driven by low dimensional chaos in a nanoscale ferromagnet*, Nature Communications **10**, 543 (2019).

[5]L. Kokkinos and J.-V. Kim, *Complex dynamics of nano-oscillators with dual vortex free layers mutually coupled via spin-torques*, arXiv preprint (2025).

[6]T. Taniguchi, *Chaotic magnetization dynamics driven by feedback magnetic field*, Physical Review B **109**, 014438 (2024).

[7]T. Kamimaki, T. Taniguchi, and H. Imamura, *Chaos in spin-torque oscillator with feedback circuit*, Physical Review B **103**, 094429 (2021).

Imaging Nanoscale Spin Wave Scattering by Quantum Magnetometry

Adam Erickson[1,*], Hanchen Wang[2], Richard Schlitz[3], Laura Van Schie[1,2], Pietro Gambardella[2], Christian Degen[1]

[1]Department of Physics, ETH Zürich, Switzerland
[2]Department of Materials, ETH Zürich, Switzerland
[3]Department of Physics, University of Konstanz, Germany

*contact: aerickson@ethz.ch

Emerging magnonic technologies rely on the propagation of dynamic collective excitations in ordered magnetic crystals as the basis for novel functional mechanisms [1]. These excitations, known as spin waves, can propagate up to millimeters in distance while retaining efficiency due to a lack of associated charge transport. Yttrium Iron Garnet (YIG) has long served as a popular host material for spin wave studies due to its very low Gilbert damping, which allows for long-range propagation. Recently, quantum sensing imaging using the Nitrogen Vacancy (NV) has been employed to directly image the dispersion of spin waves in YIG with high spatial resolution, demonstrating the dependence on excitation handedness of the microwave field, as well as the observation of frequency-degenerate wavevector contours, which are measured as interference patterns via the dipolar coupling to the electron spin resonance of the NV [2, 3]. Here, we perform nanoscale spin wave imaging and directly compare the spin wave scattering properties in YIG films grown by sputtering and liquid phase epitaxy.

REFERENCES

[1]B. Flebus, D. Grundler, B. Rana, et al., *The 2024 magnonics roadmap*, Journal of Physics: Condensed Matter **36**, 363501 (2024).

[2]I. Bertelli, J. J. Carmiggelt, T. Yu, et al., *Magnetic resonance imaging of spin-wave transport and interference in a magnetic insulator*, Science Advances **6**, `10.1126/sciadv.abd3556` (2020).

[3]B. G. Simon, S. Kurdi, J. J. Carmiggelt, et al., *Filtering and imaging of frequency-degenerate spin waves using nanopositioning of a single-spin sensor*, Nano Letters **22**, 9198–9204 (2022).

Imaging Temperature-Tuneable Spin-Wave Refraction Using Spins in Diamond

Merel Bouma[1,*]**, Pim Vree**[1]**, Toeno Van Der Sar**[1]

[1]Department of Quantum Nanoscience, Kavli Institute of Nanoscience, TU Delft, The Netherlands

*contact: m.a.bouma@tudelft.nl

Superconductors are materials with zero electrical resistivity and the ability to expel magnetic fields known as the Meissner effect. Their diamagnetic response is central to magnetic levitation and circuits such as quantum interference devices. I will describe the use of superconducting diamagnetism to shape the magnetic environment governing the transport of spin waves – collective spin excitations in magnets that are promising on-chip signal carriers – in thin-film magnets [1]. Using diamond-based magnetic imaging, we observe spin waves with strongly altered wavelengths underneath the superconductor. I will then present recent results in which we employ this wavelength shift to study temperature-tuneable spin wave refraction, which could open the way towards superconductor-based spin-wave optical devices. Our results demonstrate the versatility of superconductor-controlled spin-wave transport with potential applications in spin-wave gratings, filters, crystals and cavities.
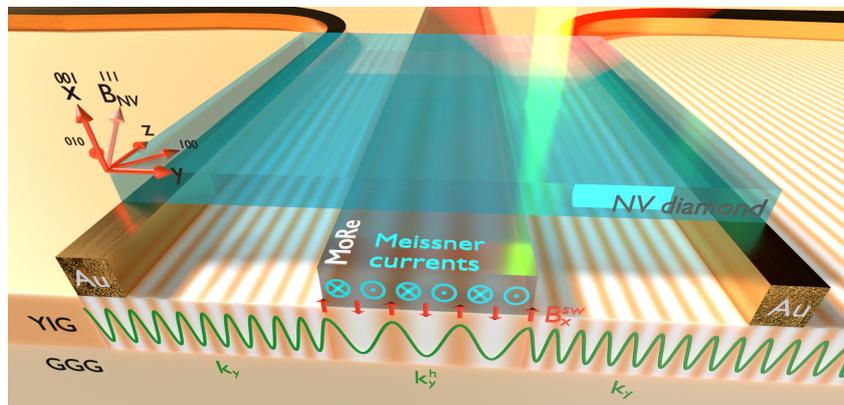
Figure 1: Spin-wavelength shift underneath a superconductor. Image retrieved from [1].

REFERENCES

[1]M. Borst, P. H. Vree, A. Lowther, et al., *Observation and control of hybrid spin-wave–meissner-current transport modes*, Science **382**, 430–434 (2023).

Impact of the Magnon Dispersion on Spin Transport

Sebastian Sailler[1,*]**, Denise Reustlen**[1]**, Michaela Lammel**[1]**, Sebastian T. B. Goennenwein**[1]**,
Richard Schlitz**[1]

[1]Universität Konstanz

*contact: sebastian.sailler@uni-konstanz.de

The spin Hall magnetoresistance (SMR) provides electrical access to the magnetization of a magnetically ordered material [1, 2]. Recent works have shown that changes in the net magnetization due to magnon creation and annihilation can be observed in the SMR [3]. However, the number of magnons - and thus the magnetization - can also be modified by changing their energy gap. In this work, we experimentally demonstrate that the changes of magnon occupation due to magnetic fields and crystal orientation sensitively modify the SMR amplitude. The concepts are summarized in Fig. 1 and highlight the close interaction between electrons, spin currents and magnons as probed by the SMR.
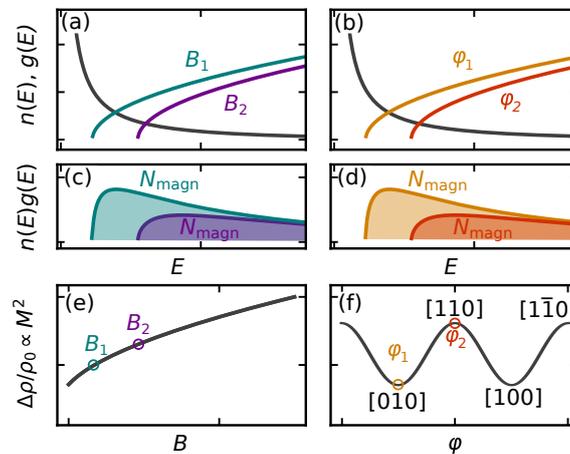
Figure 1: Theoretical expectations for the SMR amplitude. (a) and (b) illustrate the Bose-Einstein distribution $n(E)$ (black) and the density of states $g(E)$ (colored). In (a), the gap is caused by an external magnetic field B, whereas in (b), the gap is caused by the underlying crystal structure due to a crystal anisotropy of the ferromagnetic layer. (c) and (d) depict the product of $n(E) \times g(E)$. The shaded area under the graph (the integral) corresponds to the total number of magnons resulting from the different gaps. (e) and (f) depict the expected behavior of the SMR = $\Delta\rho/\rho$, accounting for a scaling with M^2 [2, 3] for different fields B_1 and B_2 or crystal orientations φ_1 and φ_2.

We investigate prototypical yttrium iron garnet / platinum heterostructures and show that higher magnetic fields reduce the magnon population by pushing the magnon manifold to higher energies, leading to an increase of magnetization and thus the SMR. In turn, the influence of the anisotropic magnon gap in yttrium iron garnet films leads to a crystal orientation dependence of the SMR. The magnetic field and orientation dependence can be rationalized in terms of the changing magnon occupation. Our results showcase that magnetoresistive effects not only probe the properties of the static magnetization, but also reveal information about the magnetization dynamics, i.e., the magnons.

REFERENCES

[1]H. Nakayama, M. Althammer, Y.-T. Chen, et al., *Spin Hall Magnetoresistance Induced by a Nonequilibrium Proximity Effect*, Physical Review Letters **110**, 206601 (2013).

[2]M. Althammer, S. Meyer, H. Nakayama, et al., *Quantitative study of the spin Hall magnetoresistance in ferromagnetic insulator/normal metal hybrids*, Physical Review B **87**, 224401 (2013).

[3]P. Noël, R. Schlitz, E. Karadža, et al., *Nonlinear Longitudinal and Transverse Magnetoresistances due to Current-Induced Magnon Creation-Annihilation Processes*, Physical Review Letters **134**, 146701 (2025).

Low-Temperature-Compatible Iron Garnet Films Grown by Liquid Phase Epitaxy

Michaela Lammel[1,*]**, Jamal Ben Joussef**[2]**, Nathan Beaulieu**[2]**, Richard Schlitz**[1]**, Davit Petrosyan**[3]**, William Legrand**[4]

[1]Department of Physics, University of Konstanz, 78457 Konstanz, Germany
[2]LabSTICC, CNRS, Université De Bretagne Occidentale, 29238 Brest, France
[3]Department of Materials, ETH Zurich, Hönggerbergring 64, 8093 Zurich, Switzerland
[4]Université Grenoble Alpes, CNRS, Institut Néel, 38042 Grenoble, France

*contact: michaela.lammel@uni-konstanz.de

Single-crystalline yttrium iron garnet (YIG) thin films are one of the prototypical material systems in the field of magnonics, owing to their record-low damping of the magnetization dynamics. Integrating such thin epitaxial YIG into hybrid (quantum) systems promises a platform to not only study the interaction of magnons with other (quasi)particles but also the realization of on-chip transduction and sensing capabilities. Up to now, epitaxial YIG with the necessary magnetic properties is almost exclusively achieved by using gadolinium gallium garnet (GGG) substrates. However, this inhibits the usability of YIG in such devices because of the losses occurring at low temperatures due to the paramagnetic substrate.

To circumvent this problem, we use liquid phase epitaxy (LPE) to grow ultrathin films of strained YIG on a commercial diamagnetic substrate, yttrium scandium gallium garnet (YSGG) [1]. We investigate their magnetization dynamics between 3 K and 300 K, and compare them to films grown on paramagnetic GGG. We demonstrate that our LPE YIG on YSGG substrates features a ferromagnetic resonance linewidth below 1 mT at 3 K, together with a very weak temperature and frequency dependence of the losses. Therewith, the growth of YIG/YSGG by LPE provides a straightforward approach for the fabrication of YIG thin films for low-temperature investigations.

REFERENCES

[1]J. B. Youssef, N. Beaulieu, R. Schlitz, et al., *Low-temperature-compatible iron garnet films grown by liquid phase epitaxy*, 2025.

Magnon Mediated Time Dynamics Transfer from Microwave to Optical Domain

Rajkumar Jadhav[1,2,3*], **Xinglin Zeng**[1], **Cedric Traub**[1,2], **Fabian Engelhardt**[1,4], **Abdullah Alabbadi**[1,2], **Arghadeep Pal**[1,2], **Pascal Del'Haye**[1,2], **Silvia Viola Kusminskiy**[1,4], **Birgit Stiller**[1,2,3]

[1]Max Planck Institute for the Science of Light, Germany
[2]Friederich - Alexander Universitat Erlangen-Nuremberg, Germany
[3]Leibnitz Universitat Hannover, Germany
[4]Institute for Theoretical Solid State Physics, RWTH Aachen University, 52074 Aachen, Germany

*contact: rajkumar.jadhav@mpl.mpg.de

Optomagnonic modulation techniques for information transfer from microwave to the optical domain have gained significant attention in recent years [1][2]. In this study, we exploit optomagnonic modulation techniques to demonstrate a real-time microwave to optical domain pulse transfer in a YIG microsphere. In our study, we inductively excite magnons using micro-loop antenna. Utilizing Brillouin light scattering, the excited magnons are then transduced to the optical domain by exciting the whispering gallery modes of the microcavity using a silica nano-fiber taper. In order to modulate the magnons, the RF signal is pulsed - which constitutes as write pulses. The optical response to pulses is encoded in the corresponding optical sidebands which is then retrieved by selective filtering and amplifying the sidebands and impinging the resulting signal on a fast photodiode. A trail of pulses is observed on a fast oscilloscope which confirms the reading of the microwave pulses in the optical domain. The study also enables a direct measurement of the lifetime of the excited magnonic mode. Access to both microwave as well as optical domains provides an opportunity of double confirmation of the lifetime. The average lifetime extracted from the decay time corresponding to the microwave domain is $\Delta_{avg,rf} = 67.55ns$ with the standard deviation of $\sigma_{rf} = 5.62ns$, while the one corresponding to the optical domain is $\Delta_{avg,opt} = 37.79ns$, with the standard deviation of $\sigma_{op} = 6.80ns$. Both lifetimes are in good agreement to each other with a relationship of $\Delta_{avg,rf} = 2 \times \Delta_{avg,op}$, which accounts for the factor of 2, resulting from measuring two different quantities - intensity in optical domain and amplitude in rf domain. The study provides an insight into the time dynamics of magnons and opens up new promising research directions such as magnon based Brillouin memory owing to a superior lifetime to its phonon counterpart at room temperature.
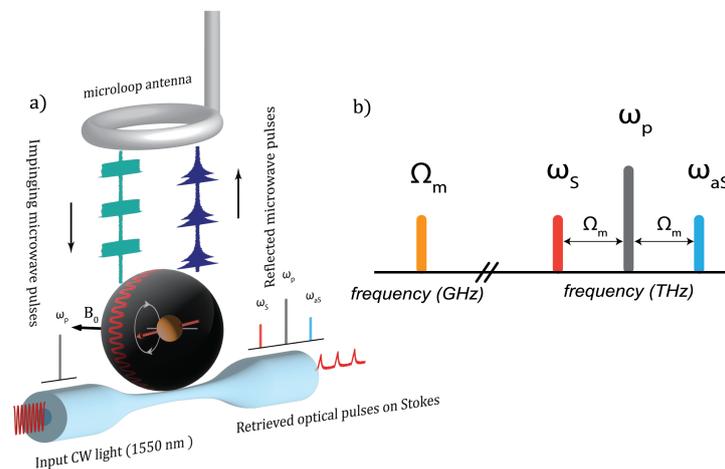

Figure 1: a) Schematics of the magnon mediated write-read scheme. b) Magnon mediated Brillouin light scattering.

REFERENCES

[1]P. Pintus, L. Ranzani, S. Pinna, et al., *An integrated magneto-optic modulator for cryogenic applications*, en, Nature Electronics **5**, Publisher: Nature Publishing Group, 604–610 (2022).

[2]N. Zhu, X. Zhang, X. Han, et al., *Waveguide cavity optomagnonics for microwave-to-optics conversion*, EN, Optica **7**, Publisher: Optica Publishing Group, 1291–1297 (2020).

Magnon-Magnon Interaction Induced by Nonlinear Spin Wave Dynamics

Álvaro Bermejillo-Seco[1,*], Matteo Arfini[1], Artem Bondarenko[2], Clinton A. Potts[1,2], Yaroslav M. Blanter[1], Herre S.J. Van Der Zant[1], Gary A. Steele[1]

[1]Quantum Nanoscience, Delft University of Technology, Netherlands
[2]Niels Bohr Institute, University of Copenhagen, Denmark

*contact: a.bermejilloseco@tudelft.nl

Most ferromagnetic resonance (FMR) experiments operate in the linear regime, where higher-order magnon processes are negligible. At higher excitation amplitudes, however, nonlinear effects such as Suhl instabilities can emerge [1]. The first nonlinear contribution, responsible for the first-order Suhl instability, involves three-magnon coupling between different spin-wave modes.

Indirect evidence of such three-magnon interactions has been reported in studies of FMR mode saturation, relaxation, and in recent cavity magnonics experiments. Yet, a systematic framework for controlling and manipulating the magnon three-wave mixing Hamiltonian remains to be developed.

In this work [2], we experimentally and theoretically demonstrate that nonlinear spin-wave dynamics can mediate an effective resonant interaction between otherwise non-resonant magnon modes in a yttrium iron garnet (YIG) disk. When the system is strongly driven near the FMR mode, we observe a clear spectral splitting that increases with drive amplitude (see Fig. 1). This behavior is quantitatively captured by a model based on the linearization of a magnon three-wave mixing Hamiltonian.

Our results provide a controlled platform for accessing and exciting higher-k magnon modes — known to possess significantly longer lifetimes [3] — and open pathways toward tunable nonlinear magnonic devices.
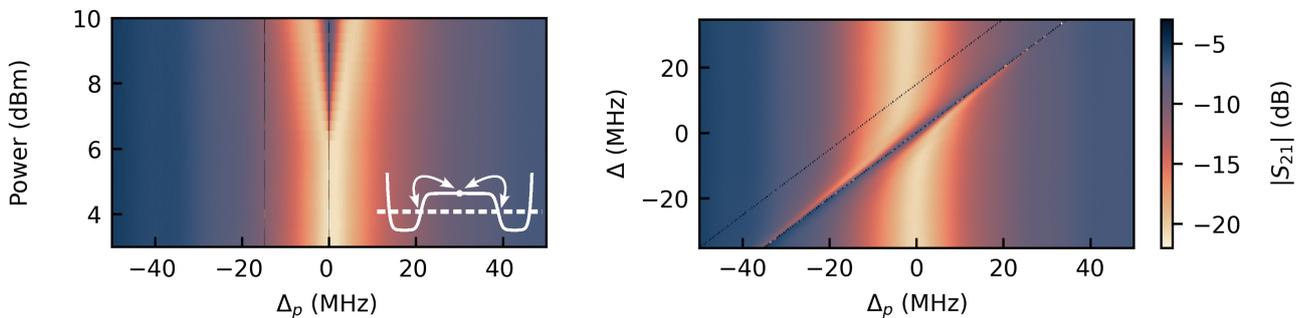

Figure 1: FMR mode splitting under strong microwave drive. Top: Power-dependent spectra with the pump tuned in resonance with the FMR mode (zero detuning), showing the tunability of the coupling strength. The diagram in the bottom-right corner shows the dispersion relation of backward volume magnons, such that the k=0 mode interacts with two modes at half frequency and opposite momenta, k. Bottom: Pump-detuning-dependent spectra at a fixed drive power of 10 dBm. The observed avoided crossing indicates strong resonant coupling between the uniform FMR mode and secondary spin-wave modes. At large detunings, the resonance dips become narrower, reflecting the lower damping of the high-k modes involved.

REFERENCES

[1]H. Suhl, *The theory of ferromagnetic resonance at high signal powers*, J. Phys. Chem. Solids **1**, 209–227 (1957).

[2]M. Arfini, A. Bermejillo-Seco, A. Bondarenko, et al., *Magnon-magnon interaction induced by nonlinear spin-wave dynamics*, Phys. Rev. Lett. **135**, 166703 (2025).

[3]R. O. Serha, K. H. McAllister, F. Majcen, et al., *Ultra-long-living magnons in the quantum limit*, arXiv:2505.22773 (2025).

Magnon-Phonon Coupling in Suspended 2D Van Der Waals Ferromagnets

Ritesh Das[1,*]**, Alvaro Bermejillo Seco**[1]**, Herre S. J. van Der Zant**[1]**, Peter Steeneken**[1,2]**,
Yaroslav M. Blanter**[1]

[1]Kavli Institute of Nanoscience, Delft University of Technology, The Netherlands
[2]Department of Precision and Microsystems Engineering, Delft University of Technology, The
Netherlands
*contact: R.D.Das@tudelft.nl

Magnomechanical systems provide a promising route for exploring quantum phenomena and hybrid information processing, but their realization has so far been limited by weak magnon–phonon coupling in conventional bulk materials. Whether two-dimensional van der Waals magnets can serve as a practical platform for such experiments remains an open question. Here we show that a suspended ferromagnetic membrane with in-plane spins and out-of-plane mechanical oscillations exhibits strong magnomechanical coupling dominated by magnetoelastic interactions. We find that the parametric single magnon–phonon coupling rate scales linearly with pre-strain and can reach a few kilohertz in van der Waals ferromagnets, specifically in CrGeTe3, under experimentally realistic conditions. This coupling rate exceeds that of YIG spheres by four orders of magnitude and surpasses phonon–photon coupling in state-of-the-art optomechanical systems by two orders of magnitude. Our results demonstrate that van der Waals magnets constitute a robust and highly tunable platform for magnomechanics, opening new opportunities for spin–lattice hybrid quantum technologies.

Manipulation of Plasmonic Response in Hybrid Magnonic Heterostructures for Spintronic Applications

C. Hernández-Gómez[1,*], C. Del Pino-Batlles[1], D. Zalka[2], N. Carmona[3], A. Gutiérrez[4], A. Quesada[1], P. Prieto[4], A. Serrano[1]

[1]Electroceramics Deparment, Ceramic and Glass Institute (ICV-CSIC), Spain
[2]Beamline BM23, European Synchrotron Radiation Facility (ESRF), France
[3]Materials Physics Department, Complutense University of Madrid (UCM), Spain
[4]Applied Physics Department, Autonomous University of Madrid (UAM), Spain

*contact: cayetano.hernandez@icv.csic.es

Spintronics is presented as a novel field for a whole new era of data processing devices, which will exploit the great properties of spin-waves (magnons) such as non-linear dynamics, low energy consumption and ultra-fast responses. In this line, hybrid magnonic systems based on plasmonic nanoparticles (NPs) and antiferromagnetic (AFM) materials show high potential to stimulate spin-waves by light through the plasmon-magnon interactions. However, developing these hybrid systems requires a detailed comprehension of physical-chemical conditions of the plasmonic NPs and their interaction with the AFM. [1, 2]

In this work, we have focused on the growth and characterization of plasmonic NPs based on noble metals (i.e., AgAu alloys) grown by solid-state dewetting (SSD) over NiO AFM bidimensional layers. The nanostructuration process of plasmonic NPs was controlled by extrinsic parameters such as temperature and partial atmosphere during the SSD process. Chemical composition of the NPs and NiO was determined and the local surface plasmon resonance (LPSR) bands were identified and associated with the different features of NPs. Specifically, a correlation between the plasmonic resonance with the morphologic properties of the NPs allows us the identification of the morphologic parameters, which have direct influence over the LSPR wavelength position and definition. Controlling these parameters opens new ways to study and control the plasmon-magnon interaction, affecting the future performance of the computing devices based on this technology.
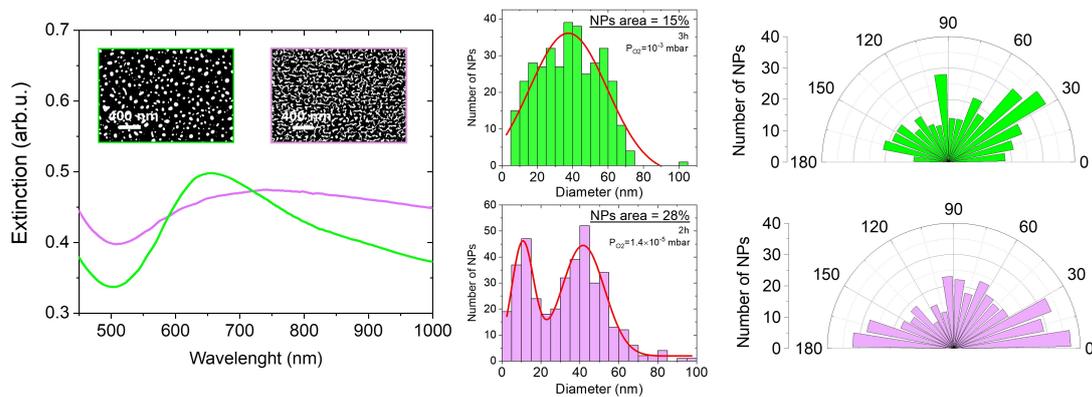

Figure 1: Left: LSPR bands obtained for two samples with different thermal treatments of Ag-Au NPs grown on NiO AFM bidimensional layers. Middle: Distributions of equivalent diameters calculated for NPs. Right: Polar distributions of the angle formed by NPs major axis with the horizontal axis.

REFERENCES

[1]A. Dyrdał, A. Qaiumzadeh, A. Brataas, and J. Barnaś, *Magnon-plasmon hybridization mediated by spin-orbit interaction in magnetic materials*, Physical Review B **108**, 10.1103/physrevb.108.045414 (2023).

[2]A. Barman, G. Gubbiotti, S. Ladak, et al., *The 2021 magnonics roadmap*, Journal of Physics: Condensed Matter **33**, 413001 (2021).

Microwave Coherent Storage Based on the Cavity Electromechanical System

Tiefu Li[1,*]

[1]School of Integrated Circuits, Tsinghua University, China

*contact: litf@tsinghua.edu.cn

The cavity optomechanical system, which studies the interaction between photons and phonons, has potential for applications in ultrasensitive detection and serves as a fundamental element in the development of general quantum networks. Here we demonstrate the coherent storage of microwave signals in the gigahertz range using a cavity electromechanical system consisting of a high-quality SiN membrane resonator and a superconducting cavity[1–3]. The membrane resonator was first cooled to its quantum ground state, where the phonon occupation number is 0.79. Subsequently, through the operations of writing, storing, and restoring, we demonstrate the coherent storage of microwave signals, which is manifested in the precise reproduction of the amplitude and phase of the written signal. The experimental results show a coherent storage time of 55 milliseconds, which means that less than one thermal noise phonon is thermalized during this interval. This suggests that cavity electromechanical systems with high-quality factors have significant potential for application in quantum storage devices for quantum computers.
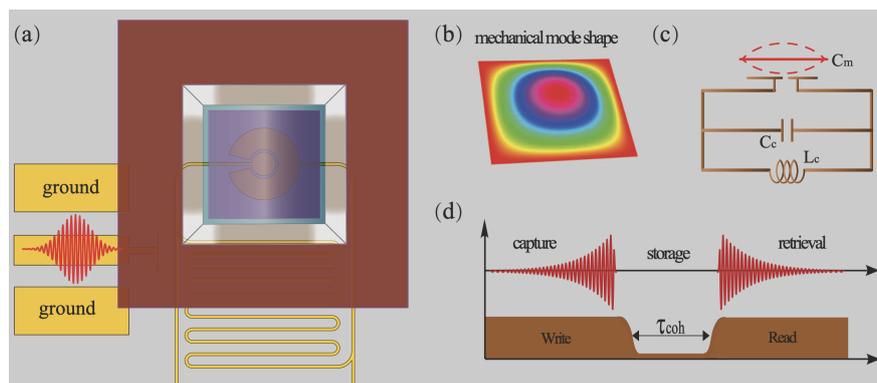
Figure 1: On-chip electromechanical memory and state tomography pulse sequence.

REFERENCES

[1]Y. Liu, Q. Liu, S. Wang, et al., *Optomechanical Anti-Lasing with Infinite Group Delay at a Phase Singularity*, Physical Review Letters **127**, 273603 (2021).

[2]Y. Liu, Q. Liu, H. Sun, et al., *Coherent memory for microwave photons based on long-lived mechanical excitations*, npj Quantum Information **9**, 80 (2023).

[3]Y. Liu, H. Sun, Q. Liu, et al., *Degeneracy-breaking and long-lived multimode microwave electromechanical systems enabled by cubic silicon-carbide membrane crystals*, Nature Communications **16**, 1207 (2025).

Nanomechanical Error Correction through the Collective Dynamics of Coupled Resonators

Nishta Arora[1,2*], **Xiaoya Jin**[1], **Christopher G. Baker**[1], **Erick Romero**[1], **Nicolas P. Mauranyapin**[1,2], **Timothy M. F. Hirsch**[1], **Glen I. Harris**[1], **Warwick P. Bowen**[1,2]

[1]School of Mathematics and Physics, The University of Queensland, Australia.
[2] ARC Centre of Excellence in Quantum Biotechnology, Queensland, Australia.

*contact: nishta.arora@uq.edu.au

Nanomechanical systems are emerging as a compelling platform for ultralow-power and radiation-tolerant information processing. A central challenge, however, is their susceptibility to bit-flip errors caused by impulsive disturbances and noise. Developing mechanical memory elements that can withstand such perturbations is therefore essential for advancing scalable nanomechanical computing.

We demonstrate that a small network of coupled nonlinear resonators can realise autonomous nanomechanical error correction [1]. Our architecture comprises three all-to-all coupled Duffing resonators fabricated from high-Q silicon nitride membranes (see Figure 1). When driven in the bistable regime, the coupled system behaves as a collective mechanical memory that naturally restores the stored state following impulsive kicks applied to a single resonator.

50μm
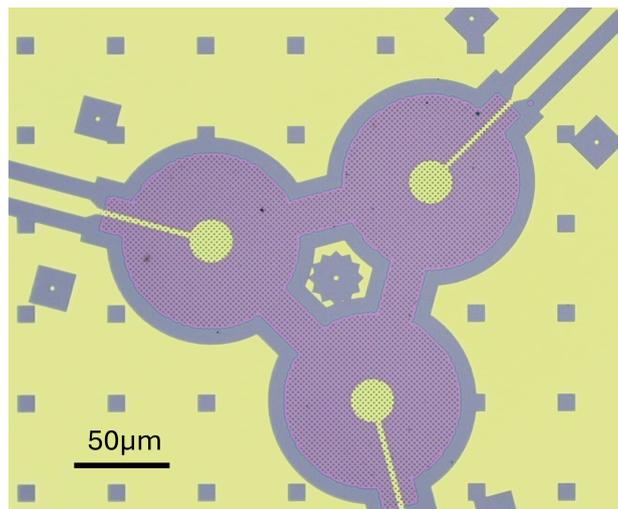
Figure 1: Optical micrograph of three coupled mechanical resonators.

Through extensive disturbance tests, we observe a 35× reduction in bit-flip probability compared with an isolated resonator operating under the same conditions. This enhanced resilience is maintained across a wide range of drive strengths and detunings, indicating the robustness of the collective state.

These results establish coupled nanomechanical resonators as a promising platform for implementing stable, low-power mechanical memory with inherent error tolerance, offering new opportunities for reliable nanomechanical processors suited to challenging operating environments.

REFERENCES

[1]X. Jin, C. G. Baker, E. Romero, et al., *Nanomechanical error correction*, arXiv preprint arXiv:2509.11560 (2025).

Origin of the Intrinsic Spin Hall Effect and Spin-Selective Berry Curvature

Diana Golovanova[1,*], **Binghai Yan**[1,2], **Tobias Holder**[3]

[1]Department of Condensed Matter Physics, Weizmann Institute of Science, Israel
[2]Department of Physics, Pennsylvania State University, United States
[3]School of Physics and Astronomy, Tel Aviv University, Israel

*contact: diana.b.golovanova@gmail.com

Although the microscopic origin of the intrinsic spin Hall effect has been identified a long time ago in terms of a spin-selective Hall voltage, the quantitative nature of this effect has remained controversial. Most importantly, it is at present still debated how to best evaluate the intrinsic spin Hall effect for band structures where spin is not a good quantum number.

Here, we propose a quantum-geometric approach for splitting a moving wave packet into its spin projections:

$$\mathcal{A}^{\alpha+}_{n,j} = \langle n|P^{\alpha+}\hat{r}_j P^{\alpha+}|n\rangle, \quad \mathcal{A}^{\alpha-}_{n,j} = \langle n|P^{\alpha-}\hat{r}_j P^{\alpha-}|n\rangle. \tag{1}$$

where $P^{\alpha+}$ and $P^{\alpha-}$ are two projectors onto spin up and spin down subspaces of α component Pauli matrices s^α, $|n\rangle = |n(\mathbf{k})\rangle$ is the Bloch wave function and position $\hat{r}_j$ can be defined in k-space through the covariant derivative. The sum $\mathcal{A}_{n,j} = \mathcal{A}^{\alpha+}_{n,j} + \mathcal{A}^{\alpha-}_{n,j}$ is then the usual Berry connection for band n, when their difference $\mathcal{A}^\alpha_{n,j} = \mathcal{A}^{\alpha+}_{n,j} - \mathcal{A}^{\alpha-}_{n,j}$ is the spin Berry connection. Using $\mathcal{A}^\alpha_{n,j}$, we introduce a novel spin shift vector:

$$\mathcal{S}^\alpha{}_{n,j}(\mathbf{k}) = \mathcal{A}^{\alpha+}_{n,j}(\mathbf{k}) - \mathcal{A}^{\alpha-}_{n,j}(\mathbf{k}) - s^\alpha_n(\mathbf{k})\mathcal{A}_{n,j}(\mathbf{k}) \tag{2}$$

where s^α_n is a diagonal matrix element of s^α. $\mathcal{S}^\alpha$ is a gauge-invariant measure of the proper distance between spin projections, which is schematically shown in Fig. 1.
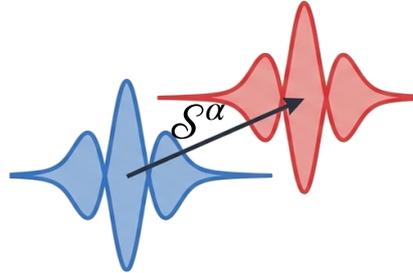

Figure 1: Shift vector as a distance between the spin up (red) part of the wave packet and the spin down one (blue).

This framework facilitates a simple and intuitive derivation of the spin-selective anomalous velocity and provides a consistent definition of the spin Berry connection and the spin-selective Berry curvature (SSBC) $\mathbf{\Omega}^\alpha_n(\mathbf{k}) = \nabla \times \mathcal{A}^\alpha_n$, whose components $(\mathbf{\Omega}^\alpha_n(\mathbf{k}))_i = \epsilon_{ijl}\Omega^\alpha_{n,jl}$ are given by,

$$\Omega^\alpha_{n,jl} = \frac{i}{2}\langle n|\{\hat{s}^\alpha, \hat{r}_j\} \times \hat{r}_l|n\rangle = \frac{i}{2}\langle n|\partial_{k_l} \times \{\hat{s}^\alpha, \partial_{k_j}\}|n\rangle. \tag{3}$$

The Spin Hall conductivity obtained from this SSBC actually reproduces the response of conserved spin current (CSC) $\frac{d}{dt}\{\mathbf{r}, \mathbf{s}^\alpha\} = \{\dot{\mathbf{r}}, \mathbf{s}^\alpha\} + \{\mathbf{r}, \dot{\mathbf{s}}^\alpha\}$ to an applied electric field [1]. The CSC preserves the continuity equation for spin even in cases where spin–orbit coupling (SOC) breaks spin conservation, $[H, s^\alpha] \neq 0$.

Unlike previous attempts, this new intrinsic spin Hall conductivity fulfills several general requirements for the transverse spin response in the gap of any topological insulator: It fulfills the continuity equation, changes continuously upon breaking spin conservation, and decreases monotonically with increasing spin-orbit torque.

REFERENCES

[1]J. Shi, P. Zhang, D. Xiao, and Q. Niu, *Proper definition of spin current in spin-orbit coupled systems*, Physical Review Letters **96**, 10.1103/physrevlett.96.076604 (2006).

Quantum Sensing of Composite Excitations of a Ferromagnet via a Qubit

Bashab Dey[1,*], Amey S. Rodge[1], Tarek Moussa[1], Akashdeep Kamra[1]

[1]Department of Physics and Research Center OPTIMAS, Rheinland-Pfälzische Technische
Universität Kaiserslautern-Landau, 67663 Kaiserslautern, Germany
*contact: bashab.dey@rptu.de

The superpositions of the quanta of bosonic modes such as photon, phonon and magnon-number states have been successfully resolved via a qubit [1–3] by engineering an effective dispersive interaction $\sim \chi \hat{n} \sigma_z$ between the qubit and the bosonic mode, where $\hat{n}$ is the boson number operator and σ_z the qubit operator [4]. When the bosonic mode hosts a superposition of its number states, the dispersive interaction renders the qubit frequency multivalued resulting in multiple resonances in the qubit spectroscopy.
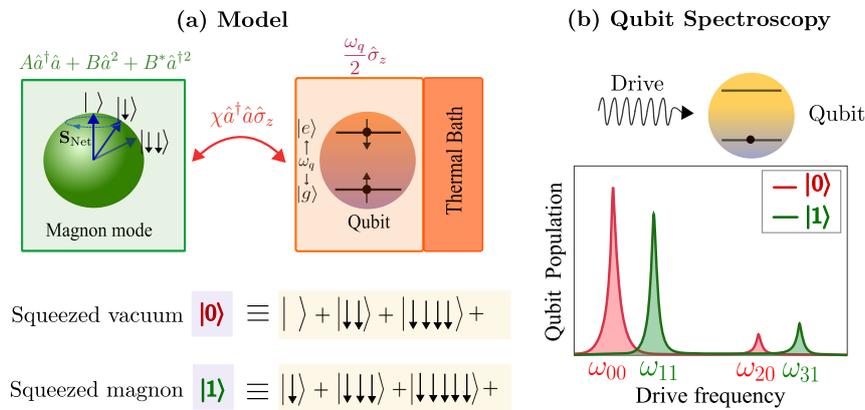
Figure 1: (a) Schematic depiction of the model and the magnonic superpositions constituting the squeezed vacuum and a squeezed magnon. (b) Qubit spectroscopy shows distinct sets of resonant peaks for each squeezed magnon number state.

The magnonic superpositions which have been sensed by a superconducting qubit [3] was a nonequilibrium state of magnons generated by driving a macroscopic ferromagnet into resonance. However, superpositions are also intrinsically present in a ferromagnet at equilibrium, forming the vacuum of *squeezed magnons* – the actual quasiparticle excitations of an anisotropic ferromagnet [5]. A recent theoretical work has shown that these equilibrium superpositions can be probed through a direct dispersive coupling to a spin qubit [6]. In our ongoing work, we extend this protocol to sense the magnonic superpositions that define the excited squeezed-magnon states. We demonstrate that qubit spectroscopy can distinguish the characteristic superpositions underlying each of these excitations. The spectroscopy is simulated using a Lindblad master equation that incorporates coupling of the system to a thermal bath. This sensing protocol provides a route to probing the quantum nature of composite magnetic excitations in a ferromagnet.

REFERENCES

[1]D. I. Schuster, A. A. Houck, J. A. Schreier, et al., *Resolving photon number states in a superconducting circuit*, Nature **445**, 515–518 (2007).

[2]P. Arrangoiz-Arriola, E. A. Wollack, Z. Wang, et al., *Resolving the energy levels of a nanomechanical oscillator*, Nature **571**, 537–540 (2019).

[3]D. Lachance-Quirion, Y. Tabuchi, S. Ishino, et al., *Resolving quanta of collective spin excitations in a millimeter-sized ferromagnet*, Science Advances **3**, e1603150 (2017).

[4]J. G. Peixoto de Faria and M. C. Nemes, *Dissipative dynamics of the Jaynes-Cummings model in the dispersive approximation: analytical results*, Phys. Rev. A **59**, 3918–3925 (1999).

[5]A. Kamra, W. Belzig, and A. Brataas, *Magnon-squeezing as a niche of quantum magnonics*, Applied Physics Letters **117**, 090501 (2020).

[6]A.-L. E. Römling, A. Vivas-Viaña, C. S. Muñoz, and A. Kamra, *Resolving nonclassical magnon composition of a magnetic ground state via a qubit*, Phys. Rev. Lett. **131**, 143602 (2023).

Spin-Wave and Mechanical Modes of Suspended YIG Microtoroids

Gabriel Soares[1,2], **G. Olivetti**[1,3], **R.L. Seeger**[2], **H. Merbouche**[2], **G. De Loubens**[2], **J. Ben Youssef**[4], **N.K.P. Babu**[5], **S.O. Valenzuela**[5], **S.W. Kurfman**[6], **G. Schimdt**[6], **B. Pigeau**[1], **O. Arcizet**[1], **T. Valet**[3], **O. Klein**[3]

[1]Istitut Néel, Grenoble, France
[2]Service De Physique De L'état Condensé, CEA Paris-Saclay, France
[3]SPINtronique Et TEchnologie Des Composants, CEA Grenoble, France
[4]Lab-STICC, Université De Brest, Brest, France
[5]Catalan Institute of Nanoscience and Nanotechnology, Campus UAB, Spain
[6]Martin-Luther-Universität Halle Wittenberg, Germany

*contact: gabriel.soares@neel.cnrs.fr

The magneto-elastic interaction couples the magnetic and elastic degrees of freedom, allowing spin-waves (SWs) and acoustic waves to hybridize [1]. Yttrium-iron-garnet (YIG) exhibits moderate magneto-elasticity and both very low SW damping and acoustic losses, which can result in strong magnon-phonon coupling in single-crystalline samples [2]. With recent advances in the nanofabrication of YIG nanoresonators [3], it can be envisioned to couple SW dynamics to mechanics in such systems. As such, it is possible to efficiently couple the mechanical modes of YIG microstructures in the very to ultra high frequency range with specific SW modes. The longer-term goal is to achieve the strong coupling regime between microwave photons, magnons, and phonons, which would enable broadband and coherent frequency conversion using this type of magneto-mechanical transducer [4].

Here, we present the mechanical and magnetic characterizations in the microwave range of suspended single crystal YIG microdisks obtained by two distinct methods: a bottom-up approach, where inductive elements are patterned near existing suspended YIG microdisks; and a top-down one, where FIB manufactured YIG microrings are transferred directly into existing inductive antennas on arbitrary substrates. The characterization of the mechanical modes of these microstructures is done with a homemade laser Michelson interferometer and the SW spectroscopy is done with a magnetic resonance force microscope. Several disks were characterized, with varying thicknesses and diameter of a few micrometers.

REFERENCES

[1]C. Kittel, *Interaction of spin waves and ultrasonic waves in ferromagnetic crystals*, Phys. Rev. **110**, 836–841 (1958).

[2]K. An, A. N. Litvinenko, R. Kohno, et al., *Coherent long-range transfer of angular momentum between magnon kittel modes by phonons*, Phys. Rev. B **101**, 060407 (2020).

[3]F. Heyroth, C. Hauser, P. Trempler, et al., *Monocrystalline freestanding three-dimensional yttrium-iron-garnet magnon nanoresonators*, Phys. Rev. Appl. **12**, 054031 (2019).

[4]F. Engelhardt, V. Bittencourt, H. Huebl, O. Klein, and S. V. Kusminskiy, *Optimal broadband frequency conversion via a magnetomechanical transducer*, Phys. Rev. Appl. **18**, 044059 (2022).

Spin-Wave Excitation in Ferromagnet with Superconductive Nanostructures

E. Pribytova[1,*], **J. Klíma**[2], **J. Holobrádek**[2], **J. Kharlan**[3], **J. Klos**[3], **M. Urbánek**[2]

[1]Institute of Physical Engineering, Brno University of Technology, Czechia
[2]CEITEC BUT, Brno University of Technology, Czechia
[3]ISQI, Faculty of Physics, Adam Mickiewicz University, Poland

*contact: 238576@vutbr.cz

A growing interest in hybrid systems for quantum computing necessitates the operation of magnonic conduits at low temperatures and in superconducting circuit environments. In such systems, eddy currents in superconductors shield the internal magnetic field, leading to the formation of an external stray field. This stray field, which can be controlled by an external dynamic magnetic field, can influence the magnetization dynamics of nearby magnetic layers and structures [1], [2]. In our study, we investigate the impact of stray magnetic fields generated by superconducting stripe arrays on spin-waves excited in an adjacent ferromagnetic layer. We have conducted a series of experiments on a hybrid system consisting of superconducting strips placed over a magnetic film.

The sample was cooled down in a cryogenic system to explore a broad temperature range, including temperatures below and above the critical temperature of niobium (9 K). Figure 1a shows the arrangement of experiment. A homogeneous RF magnetic field in the frequency range of 0–15 GHz was applied using a Vector Network Analyzer (VNA), which simultaneously recorded the absorption response of the magnetic layer. The measured absorption spectra across 5–270 K Figure 1c are complemented by theoretical calculations performed using the SpinWaveToolkit Python package [3].
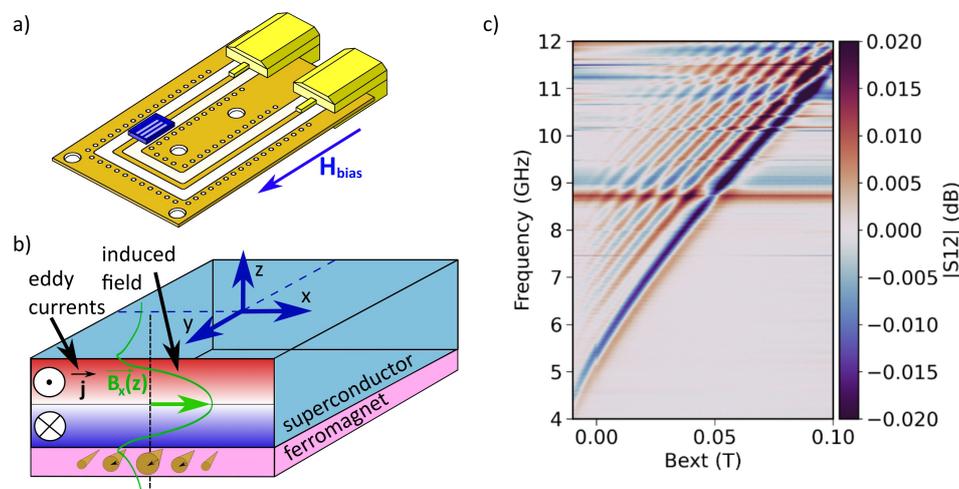

Figure 1: The scheme of experiment and received spin waves spectra. a) Geometry for performed low-temperature measurements. b) Scheme of physical process inside superconducting stripe. Dynamic component of external magnetic field induces eddy currents j. Eddy currents produce dynamic field B. c) Spectra of spin waves produced by influence of stripes in superconductive state

REFERENCES

[1]J. Kharlan, K. Szulc, J. W. Kłos, et al., *Tunable magnonic crystal in a hybrid superconductor–ferrimagnet nanostructure*, Scientific Reports **14**, 25594 (2024).

[2]J. Kharlan, K. Sobucki, K. Szulc, S. Memarzadeh, and J. W. Kłos, *Spin-wave confinement in a hybrid superconductor-ferrimagnet nanostructure*, Phys. Rev. Appl. **21**, 064007 (2024).

[3]O. Wojewoda and J. Klíma, *Spinwavetoolkit: set of tools useful in spin wave research*, en, version 1.2.0, (2025) https://github.com/CEITECmagnonics/SpinWaveToolkit.

Spin-Wave Spectroscopy of Perpendicularly Magnetized Disks

Gauthier Debuisschert[1,*], Kei Yamamoto[2], Benamin Pigeau[3], Olivier Klein[1]

[1]SPINTEC, Université Grenoble Alpes, CEA, CNRS, Grenoble INP, Grenoble, France
[2]Advanced Science Research Center, JAEA, Tokai, Ibaraki 319-1195, Japan
[3]Institut Néel, Université Grenoble Alpes, CNRS, Grenoble INP, Grenoble, France

*contact: gauthier.debuisschert@cea.fr

There has been an increasing realization in recent decades of the fundamental importance of the angular momentum carried by wave fields, which can be separated into spin (SAM) and orbital (OAM) components in certain cases. The latter is a universal feature of waves in uniform continuum media represented by helical or rotational wavefronts, and can potentially encode a large amount of information for mode multiplexed communication channels or multi-level registers of quantum states.

We have recently developed a homemade ferromagnetic resonance (FMR) spectrometer to investigate magnetization dynamics in axially symmetric geometries. In the saturated state, this angular momentum can be decomposed into orbital and spin contributions [1, 2], which are coupled through the dynamical dipole–dipole interaction.

In this work, we report spin-wave spectroscopy measurements on perpendicularly magnetized microdisks [3–5] of yttrium iron garnet (YIG) excited by circularly polarized microwave magnetic fields. The absorption spectrum is shown in Figure.1. We investigate how the precession ellipticity depends on the azimuthal mode index and its polarization under varying external magnetic field conditions.
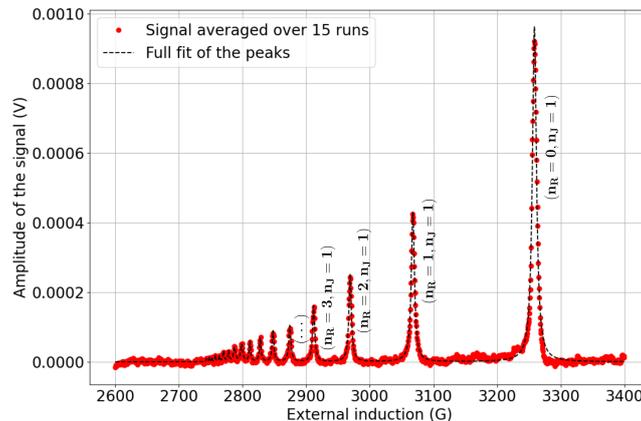

Figure 1: Spin-wave absorption as a function of the applied magnetic field with an excitation frequency of $6\,\mathrm{GHz}$ for a $200\,\mu\mathrm{m}$-wide and $21\,\mu\mathrm{m}$-thick YIG disk. The resonance peaks are labeled (n_R, n_J), where n_R denotes the radial index and n_J the azimuthal index. The strongest peak is the Kittel mode, labeled $(0, 1)$. The other peaks are the radial harmonics.

REFERENCES

[1]T. Valet, K. Yamamoto, B. Pigeau, G. de Loubens, and O. Klein, *The orbital angular momentum of azimuthal spin-waves*, 10.48550/ARXIV.2503.06556 (2025).

[2]T. Valet, K. Yamamoto, B. Pigeau, G. de Loubens, and O. Klein, *Field theory of linear spin-waves in finite textured ferromagnets*, 10.48550/ARXIV.2503.06557 (2025).

[3]T. Yukawa and K. Abe, *FMR spectrum of magnetostatic waves in a normally magnetized YIG disk*, Journal of Applied Physics **45**, 3146–3153 (1974).

[4]V. Charbois, V. V. Naletov, J. B. Youssef, and O. Klein, *Mechanical detection of ferromagnetic resonance spectrum in a normally magnetized yttrium–iron–garnet disk*, Journal of Applied Physics **91**, 7337 (2002).

[5]O. V. Dobrovolskiy, S. A. Bunyaev, N. R. Vovk, et al., *Spin-wave spectroscopy of individual ferromagnetic nanodisks*, (2020).

NV-Center Spectroscopy of Spin-Wave Eigenmodes in Normally Magnetized Microdisks

Fourniols Clément[1,*]**, Umeda Maki**[1,2]**, Clot Eric**[1]**, Pigeau Benjamin**[3]**, Klein Olivier**[1]

[1]Université Grenoble Alpes, CEA, CNRS, Grenoble INP, Spintec, Grenoble, France
[2]Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Ibaraki, Japan
[3]Université Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, Grenoble, France

*contact: clement.fourniols@cea.fr

Over the past decade, scanning nitrogen–vacancy (NV) center magnetometry has emerged as a powerful technique for locally probing both static and dynamic magnetic fields. Although static magnetization imaging has already reached maturity [1], the detection and mapping of magnetization dynamics remain in their early stages.

Traditionally, NV-based broadband detection of spin waves (SWs) has relied on multi-magnon scattering processes triggered by ferromagnetic resonance (FMR), which generate magnons at the NV electron spin resonance (ESR) frequency [2]. However, this approach strongly depends on the relative position of the magnon band with respect to the NV ESR transition and therefore cannot be applied systematically across materials or field configurations. Moreover, extracting quantitative information about the excited SW modes is challenging, as it inherently requires operating in the nonlinear regime.

Using double-tone spectroscopy, we optically detect the linear spin-wave eigenmodes of a microdisk with a single NV center. The measurements are carried out at room temperature on a normally magnetized yttrium iron garnet (YIG) disk with an 80 μm radius and a thickness of 4 μm. The diamond probe contains an NV center whose quantization axis is oriented along the (111) crystallographic direction, aligned with the externally applied magnetic field.

The detection principle is based on the modulation of the NV electron spin resonance induced by the microwave-driven oscillation of the stray magnetic fields generated by the spin-wave modes. As shown in Fig. 1, this approach enables MHz-level spectral sensitivity for the detection of ferromagnetic resonances.
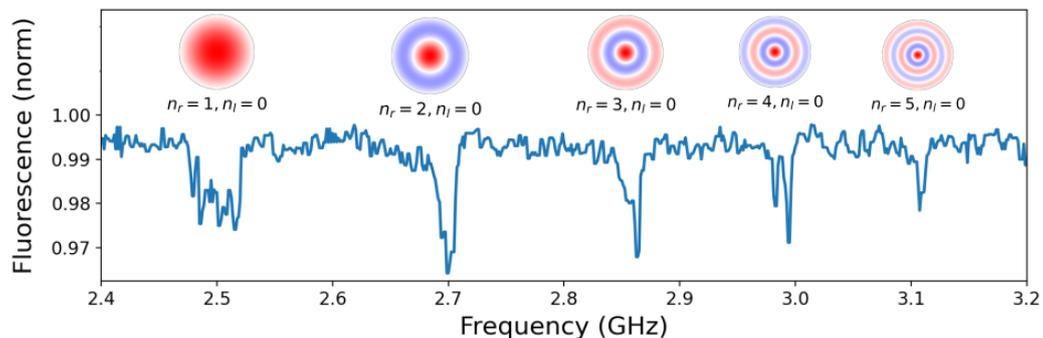

Figure 1: Single NV-center spin-wave spectroscopy performed with the probe positioned at the center of the YIG microdisk under a 240 mT out-of-plane magnetic bias field. The dominant resonance corresponds to the Kittel mode, while the subsequent peaks arise from higher-order radial harmonics. Schematic representations of the corresponding precession profiles are shown above their respective spectral features.

REFERENCES

[1]P. Welter, B. Jósteinsson, S. Josephy, et al., *Fast scanning nitrogen-vacancy magnetometry by spectrum demodulation*, Physical Review Applied **19**, 034003 (2023).

[2]B. A. McCullian, A. M. Thabt, B. A. Gray, et al., *Broadband multi-magnon relaxometry using a quantum spin sensor for high frequency ferromagnetic dynamics sensing*, Nature Communications **11**, 10.1038/s41467-020-19121-0 (2020).

Table of Contents by Author