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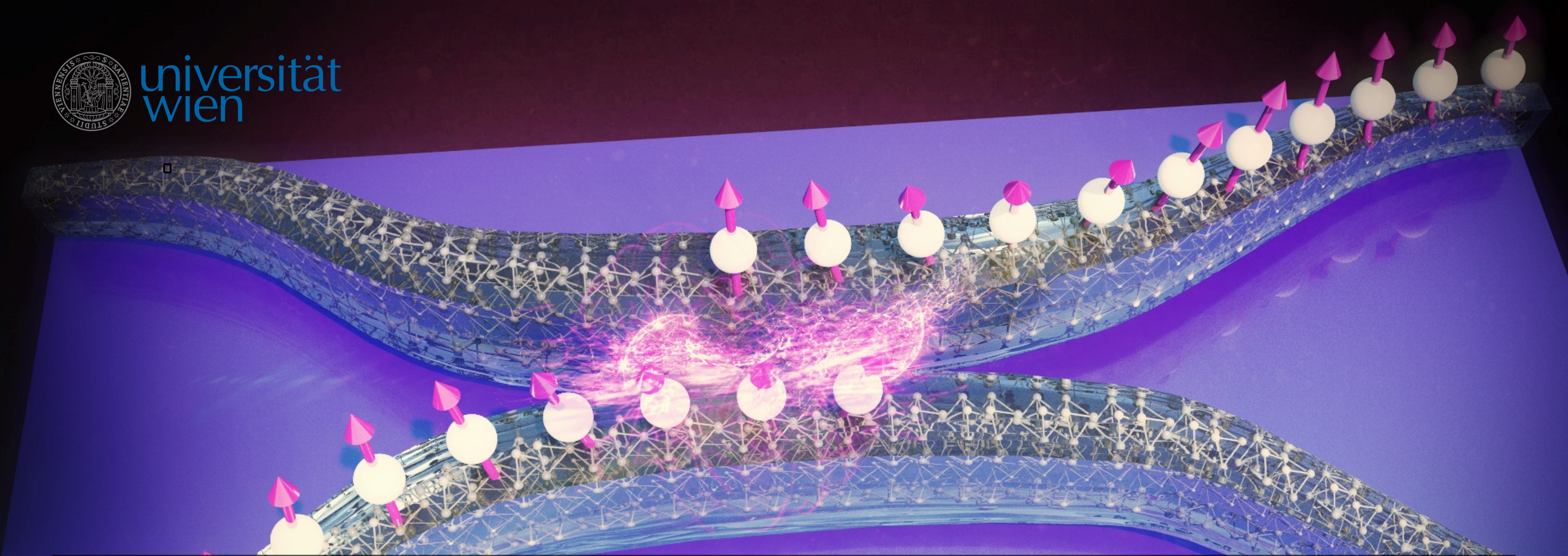

3D and inverse-design magnonics

Andrii Chumak
Nanomagnetism and Magnonics Group
Faculty of Physics, University of Vienna, Austria

erc
FWF
Der Wissenschaftsfonds

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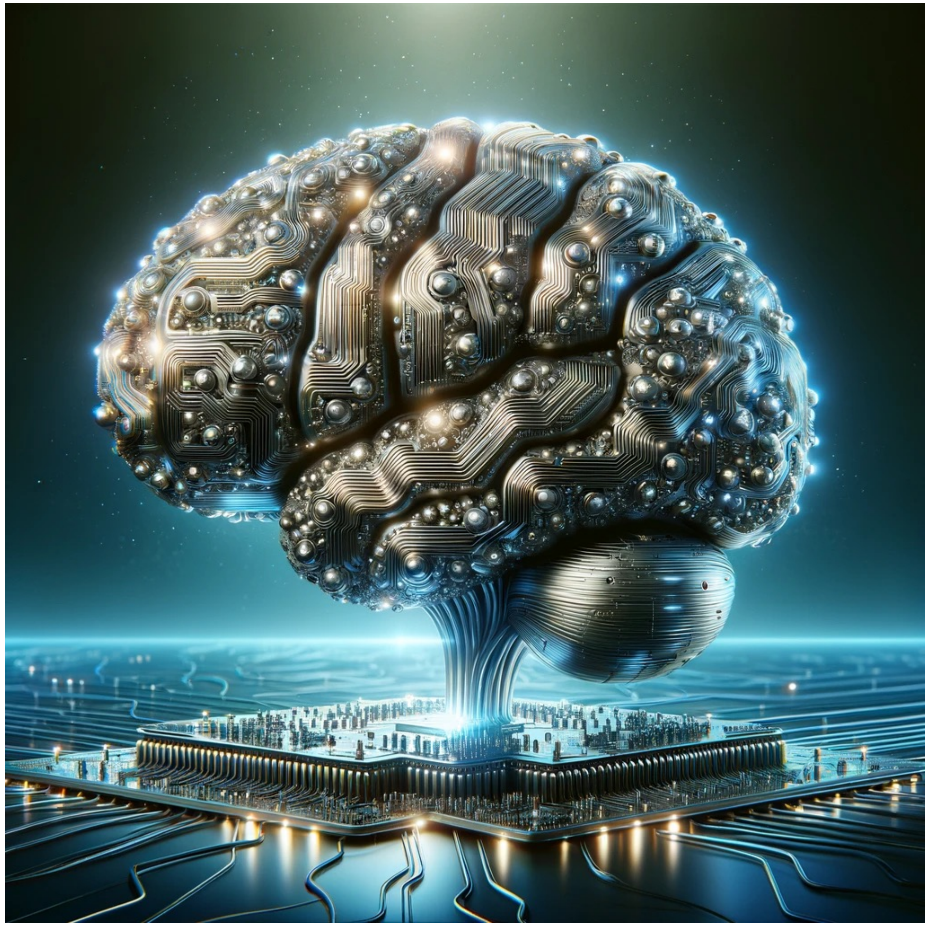
3D magnonics

High quantity of elements + new physics

Inverse-design magnonics

Any type of computing, incl. neuromorphic



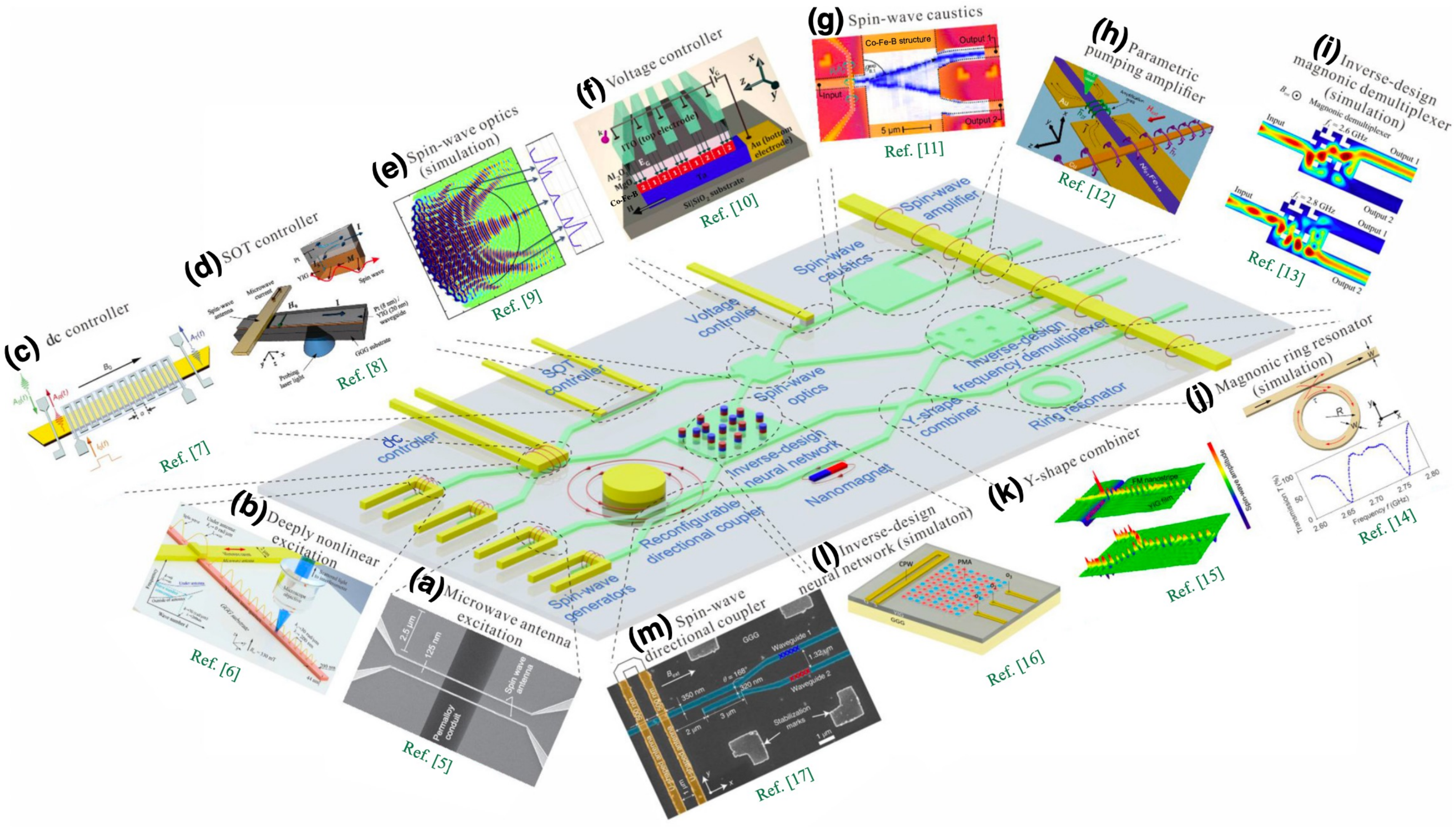
ChatGPT4:
“magnonic computer that looks like a human brain”

The field of magnonics

Nanoscale magnonic networks

PHYSICAL REVIEW APPLIED **21,** 040503 (2024)

Perspective



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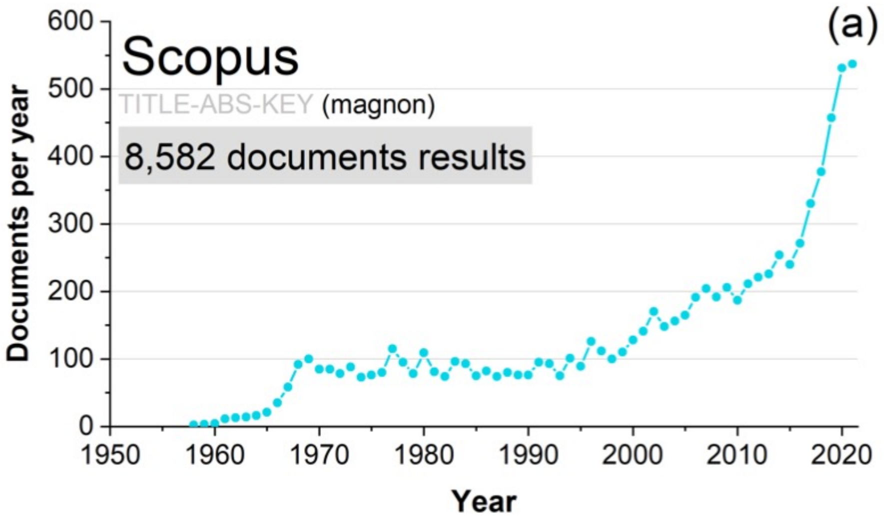
Roadmap on spin-wave computing

IEEE TRANSACTIONS ON MAGNETICS, VOL. 58, NO. 6, JUNE 2022 0800172

Advances in Magnetics

Roadmap on Spin-Wave Computing

A. V. Chumak[1], P. Kabos[2], *Life Fellow, IEEE*, M. Wu[3], *Fellow, IEEE*, C. Abert[1,4], C. Adelmann[5], A. O. Adeyeye[6], J. Åkerman[7], F. G. Aliev[8], A. Anane[9], A. Awad[7], C. H. Back[10], A. Barman[11], G. E. W. Bauer[12,13], M. Becherer[14], E. N. Beginin[15], V. A. S. V. Bittencourt[16], Y. M. Blanter[17], P. Bortolotti[9], I. Boventer[9], D. A. Bozhko[18], S. A. Bunyaev[19], J. J. Carmiggelt[17], R. R. Cheenikundil[20], F. Ciubotaru[5], S. Cotofana[21], G. Csaba[22], O. V. Dobrovolskiy[1], C. Dubs[23], M. Elyasi[12], K. G. Fripp[24], H. Fulara[25], I. A. Golovchanskiy[26,27], C. Gonzalez-Ballestero[28,29], P. Graczyk[30], D. Grundler[31], P. Gruszecki[32], G. Gubbiotti[33], K. Guslienko[34,35], A. Haldar[36], S. Hamdioui[21], R. Hertel[20], B. Hillebrands[37], *Fellow, IEEE*, T. Hioki[12], A. Houshang[7], C.-M. Hu[38], H. Huebl[39], M. Huth[40], E. Iacocca[18], M. B. Jungfleisch[41], G. N. Kakazei[19], A. Khitun[42], R. Khymyn[7], T. Kikkawa[43], M. Kläui[44], O. Klein[45], J. W. Kłos[32], S. Knauer[1], S. Koraltan[1], M. Kostylev[46], M. Krawczyk[32], I. N. Krivorotov[47], V. V. Kruglyak[24], D. Lachance-Quirion[48], S. Ladak[49], R. Lebrun[9], Y. Li[50], M. Lindner[23], R. Macêdo[51], S. Mayr[52,53], G. A. Melkov[54], S. Mieszczak[32], Y. Nakamura[55,56], H. T. Nembach[2,57], A. A. Nikitin[58], S. A. Nikitov[59], V. Novosad[50], J. A. Otálora[60], Y. Otani[61,62], A. Papp[22], B. Pigeau[63], P. Pirro[37], W. Porod[64], *Life Fellow, IEEE*, F. Porrati[40], H. Qin[65], B. Rana[32], T. Reimann[23], F. Riente[66], O. Romero-Isart[28,29], A. Ross[9], A. V. Sadovnikov[15], A. R. Safin[59], E. Saitoh[12,43,67], G. Schmidt[68,69], H. Schultheiss[70], K. Schultheiss[70], A. A. Serga[37], S. Sharma[16], J. M. Shaw[2], D. Suess[1,4], O. Surzhenko[23], K. Szulc[32], T. Taniguchi[10], M. Urbánek[71,72], K. Usami[55], A. B. Ustinov[58], T. van der Sar[17], S. van Dijken[65], V. I. Vasyuchka[37], R. Verba[73], S. Viola Kusminskiy[16,74], Q. Wang[1], M. Weides[51], M. Weiler[37], S. Wintz[75], S. P. Wolski[55], and X. Zhang[76,77]



- ✓ 116 authors
- ✓ 61 sections
- ✓ 57 figures
- ✓ 530 references

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Spin waves for novel information systems

Boolean spin wave logic gates and magnonic conduits

Diodes and circulators, rf units, interferometers, valleytronics, majority gates, directional couplers, half-adder, 32-bit ripple carry adder, circuitry, amplifier designs, and interfacing

Magnonic unconventional computing

Neuromorphic computing, holographic memory, inverse-design magnonics, nonlinear phenomena, Ising machines

Towards quantum magnonics

BEC, quantum YIG, polarons, nano-resonators, cavity magnonics, planar hybrid circuits, entangled magnons, hybrid interactions, ultra-strong photon-to-magnon coupling, quantum interfaces, superconducting qubits

3D building blocks for magnonic networks

3D YIG nano-structures, Ni nano-tubes, FEBID and FIBID, 3D ASI, 3D interconnects and magn. crystals

Low-energy manipulation and amplification of spin waves

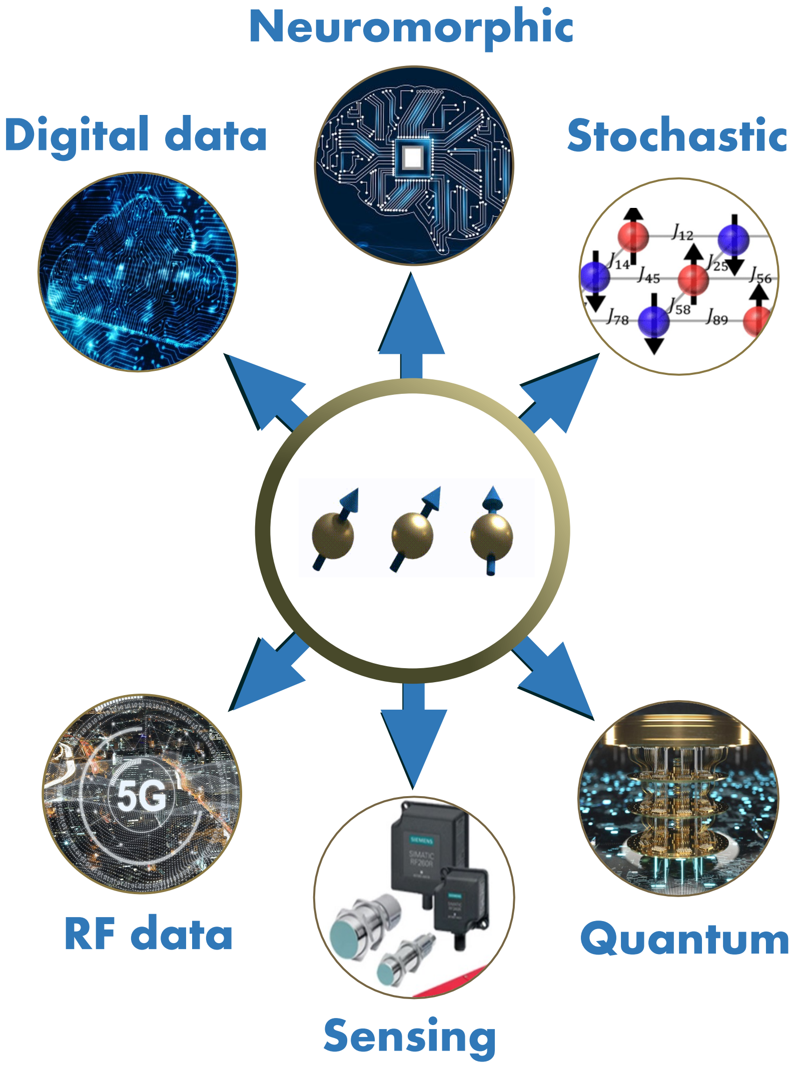
VCMA, multiferroics, ferrite-ferroelectric and ferrite-piezoelectric hybrids, magnon fluxonics

2D building blocks for magnonic networks

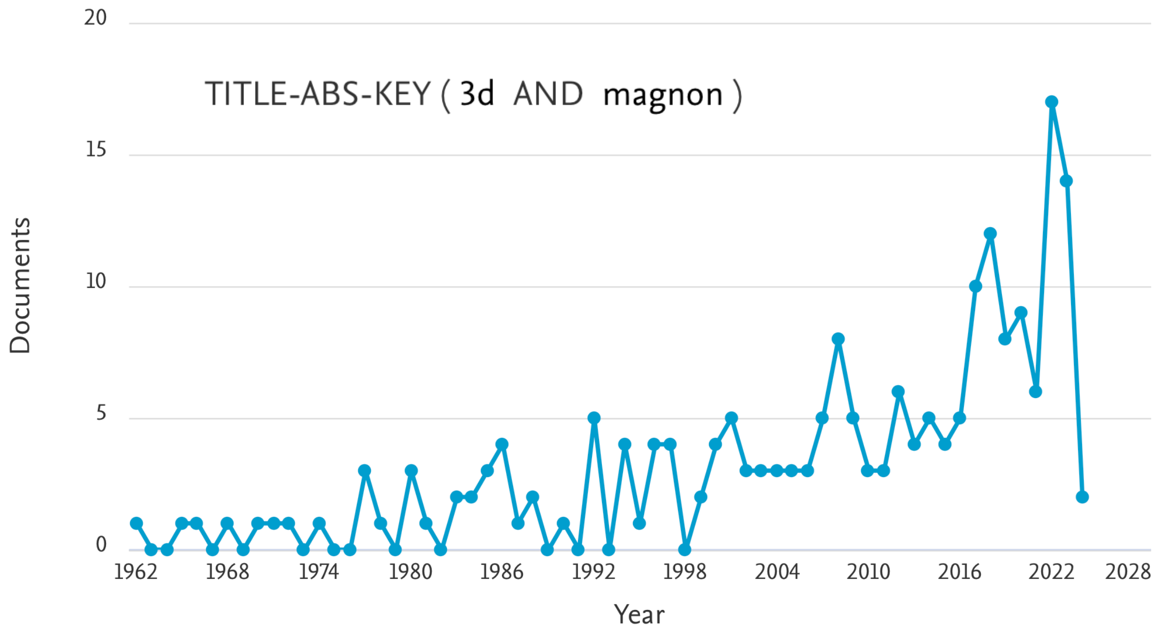
Conversion, superconductor hybrids, resonators, curved waveguides, controlled anisotropy, STIRAP

Magnonics at the nanoscale

YIG, $Co_{25}Fe_{75}$, ASI, bias-free nanomagnets, simulations, AFMs, NV magnetometry



3D magnonics



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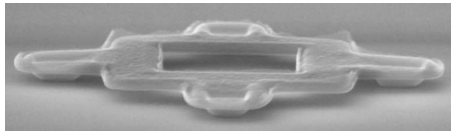
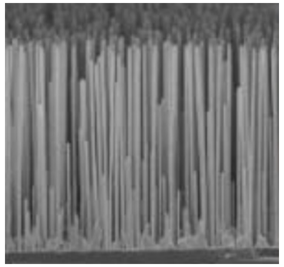
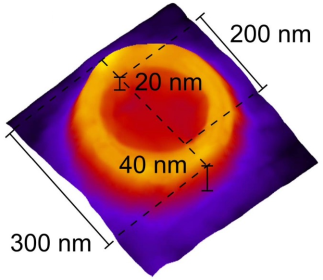
Chapter IV. 3D BUILDING BLOCKS FOR MAGNONIC NETWORKS



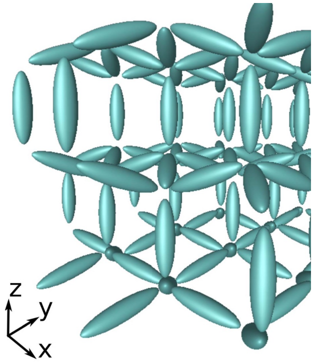


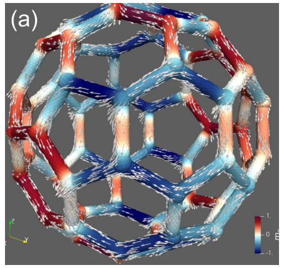
IVA. 3D YIG Nanostructures
G. Schmidt

IVB. Conformal Ferromagnetic Coatings for Tubular Magnon Conduits and 3D Magnonic Networks
D. Grundler and J. A. Otalora



IVC. Direct-Write 3D Magnonic Nano-Architectures
O. Dobrovolskiy, F. Porrati, and M. Huth



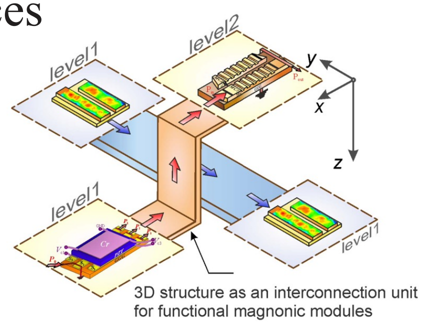


IVD. Magnonics in 3D Magnetic Meta-Materials
S. Koraltan, C. Abert, and D. Suess

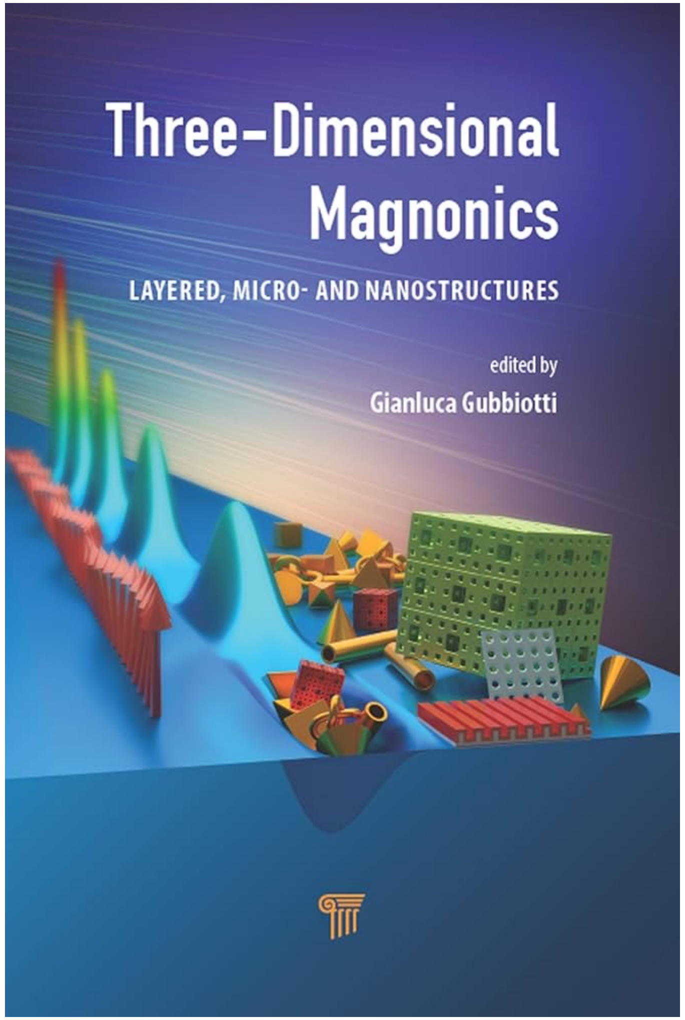
IVE. Magnonics in 3D Magnetic Meta-Materials
R.R. Cheenikundil and R. Hertel

IVF. Magnetic Charge Transport and Spin-Wave Propagation in 3D Nanostructured Lattices
S. Ladak and A. Barman

IVG. 3D Magnonic Crystals and Interconnects
G. Gubbiotti, A.V. Sadovnikov, E. N. Beginin, S. A. Nikitov, C. Adelmann, and F. Ciubotaru



Three-Dimensional Magnonics, edited by G. Gubbiotti, 2019



Journal of Applied Physics | PERSPECTIVE | scitation.org/journal/jap

Prospects toward flexible magnonic systems

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Published Online: 18 October 2021

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D. Faurie,[1,a] A. O. Adeyeye,[2,3] and F. Zighem[1,b]

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[b]**Electronic address:** zighem@univ-paris13.fr

Three-Dimensional Magnonics, edited by G. Gubbiotti, 2019

Why 3D magnonics?

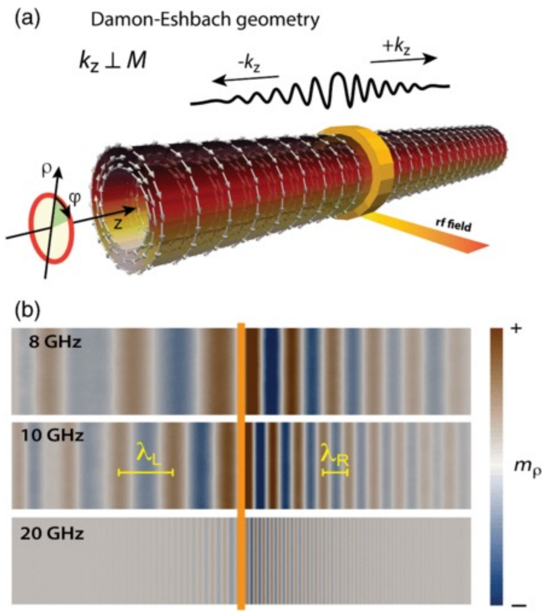
Motivation befind 3D magnonics

Number of data processing units	No problems with heating	Access to new physics

10x10x10 nm^3 unit
1x1 mm^2 chip, one layer: 10^{10} units
1x1x1 mm^3 chip: 10^{15} units

Parameters	YIG[a] (100 nm)	YIG[b] (30 nm)	CMOS[c] (7 nm)
Area (μm^2)	5.58	1.016	1.024
Delay time (ns)	150	18	6×10^{-2}
Total energy consumption without amplification (aJ)	24.6	1.96	35.3

Wang, et al., Nature Electronics 3, 765 (2020)



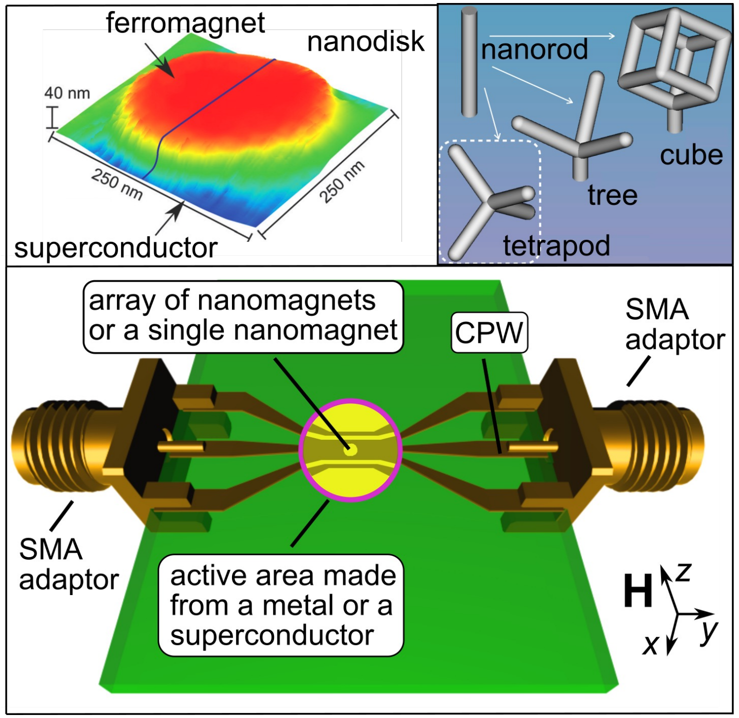
Otálora, et al., Phys. Rev. Lett. 117, 227203 (2016)

Nanomagnetism and Magnonics

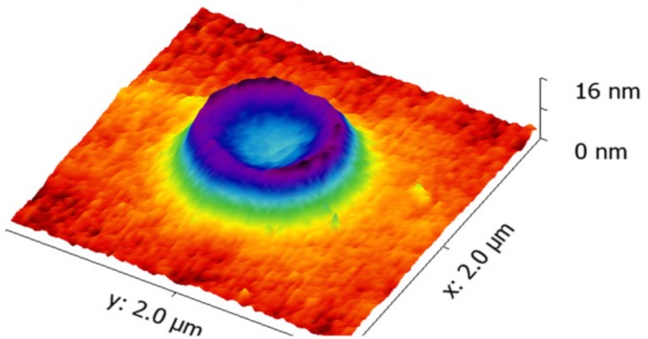
1st row: Noura Zenbaa, Andrii Chumak, Qi Wang, **Oleksandr Dobrovolskiy**, Barbora Budinská;
2nd row: Rostyslav Serha, Andrey Voronov, Khrystyna Levchenko, Fabian Majcen, **Sebastian Lamb-Camarena**, Pedro del Real;
3rd row: Richard Emberger, Sebastian Knauer, Simon Peinhaupt, Clemens Schmid; 4th row: David Schmoll, Andreas Höfinger, Aram Sajdak

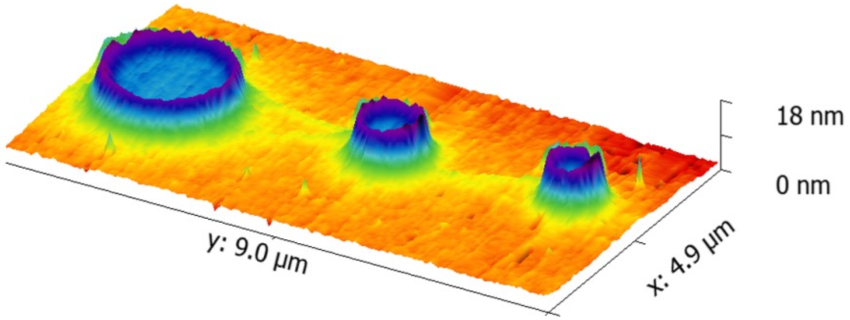
Engineered nano-volcanoes

Microwave spectroscopy of 3D nanomagnets

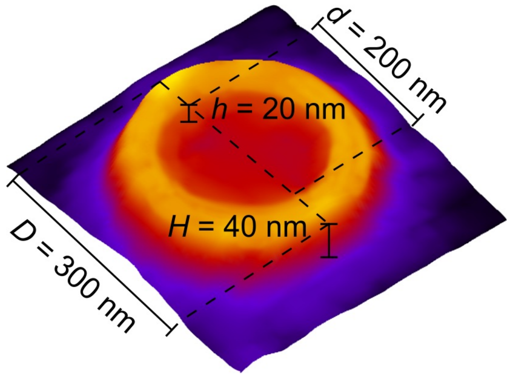


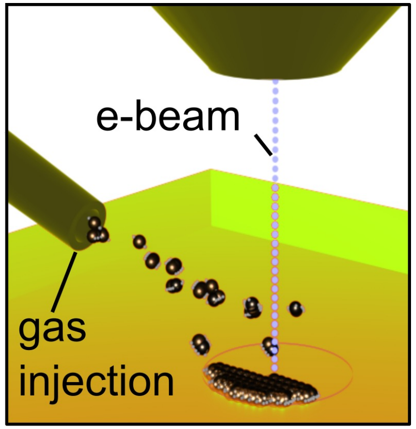
Nanodisks with crowns [depleted-precursor writing regime]



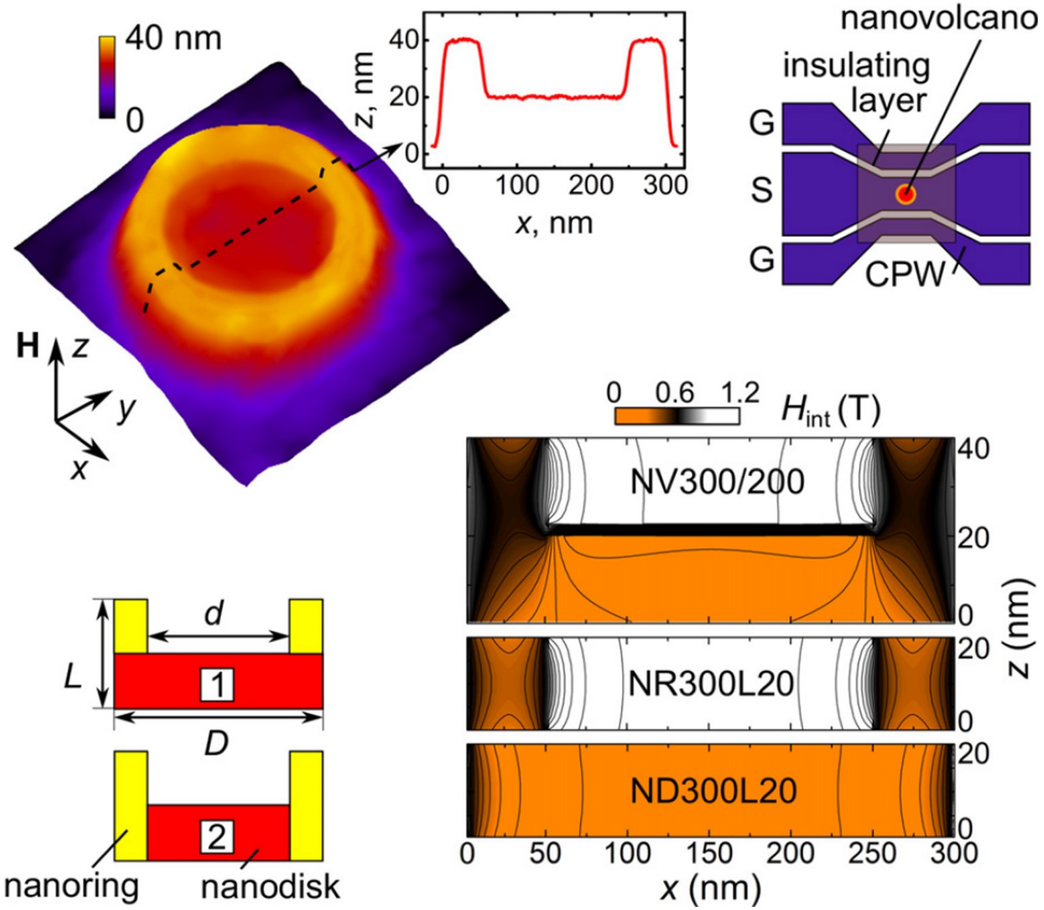


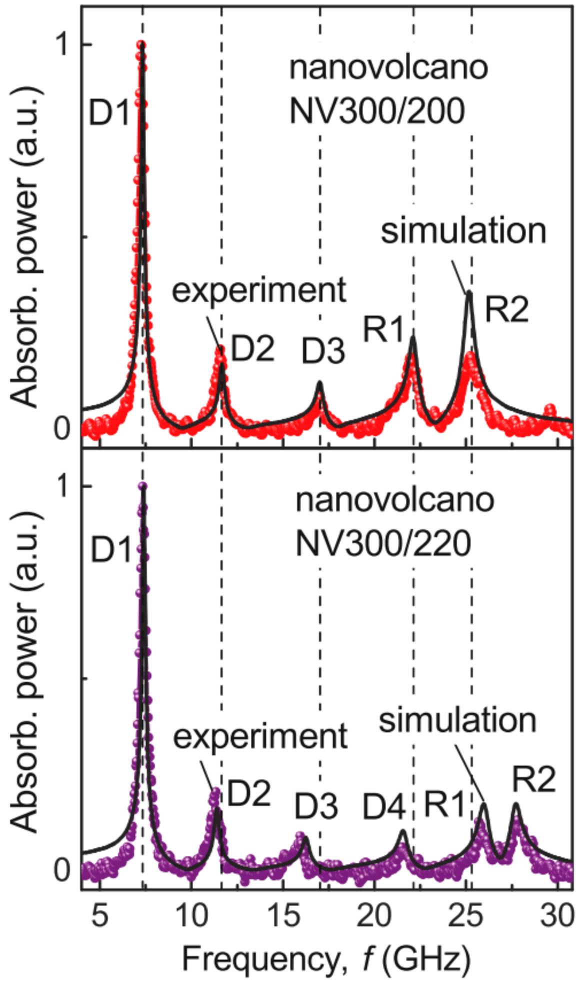
Designed nano-volcanoes





3D case: “Drum modes” in nanovolcanoes



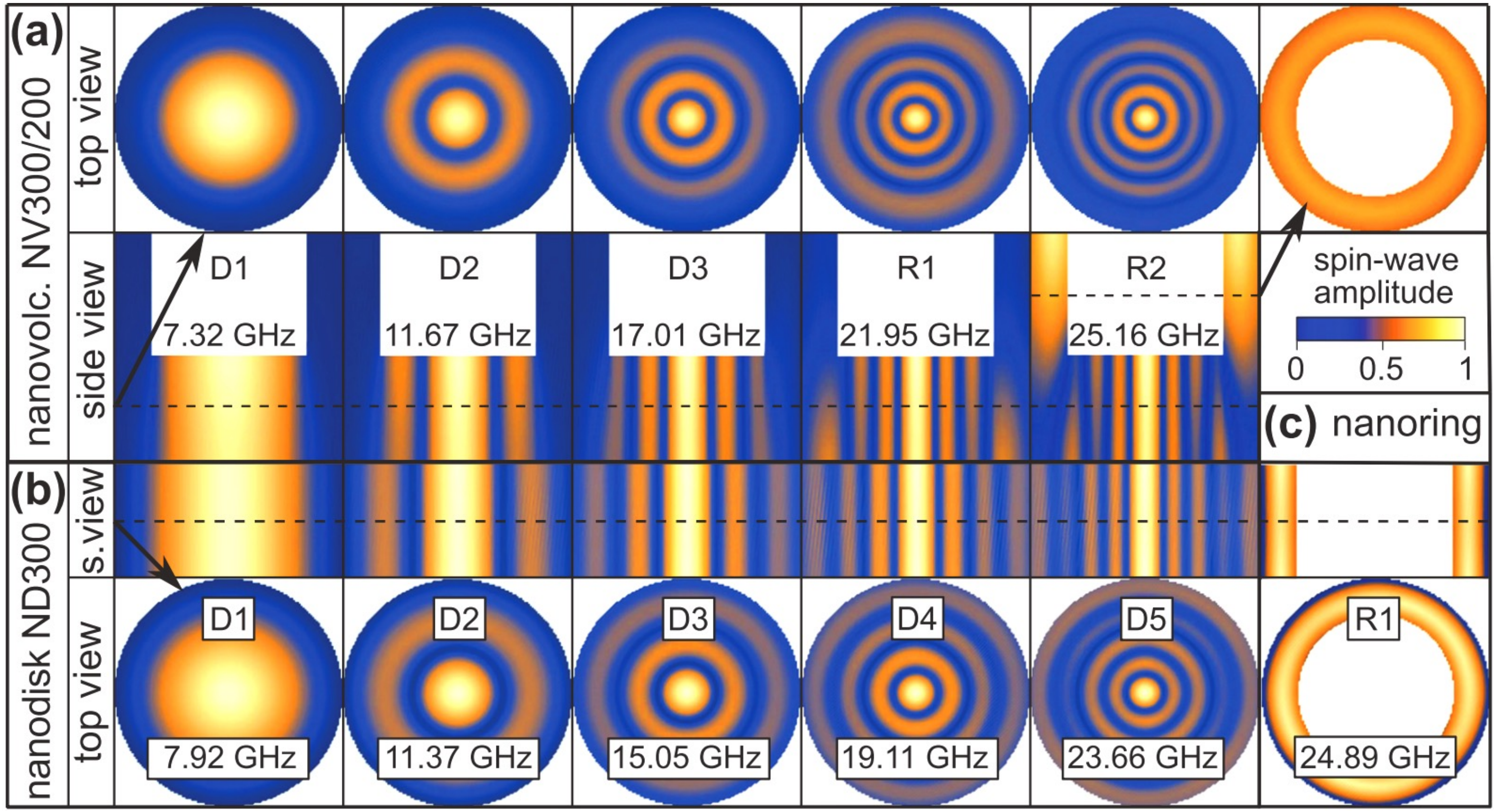


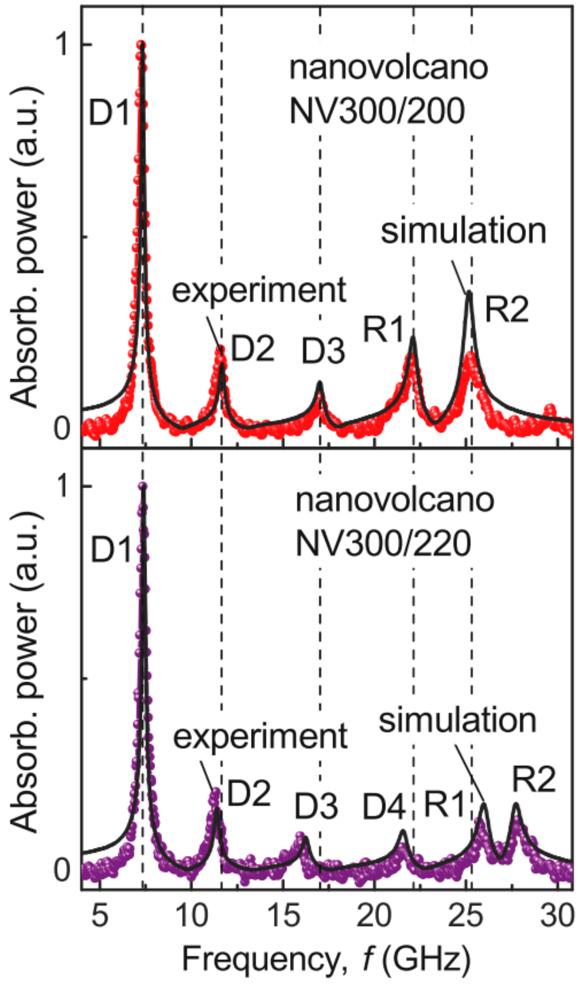
Nonuniform demag. field !

Dobrovolskiy, et al., APL 118, 132405 (2021)

Mode profiles in nanovolcanoes

MuMax3 simulations





- Low-frequency modes: volcano crater
- High-frequency modes: ring around crater

Dobrovolskiy, et al., APL 118, 132405 (2021)

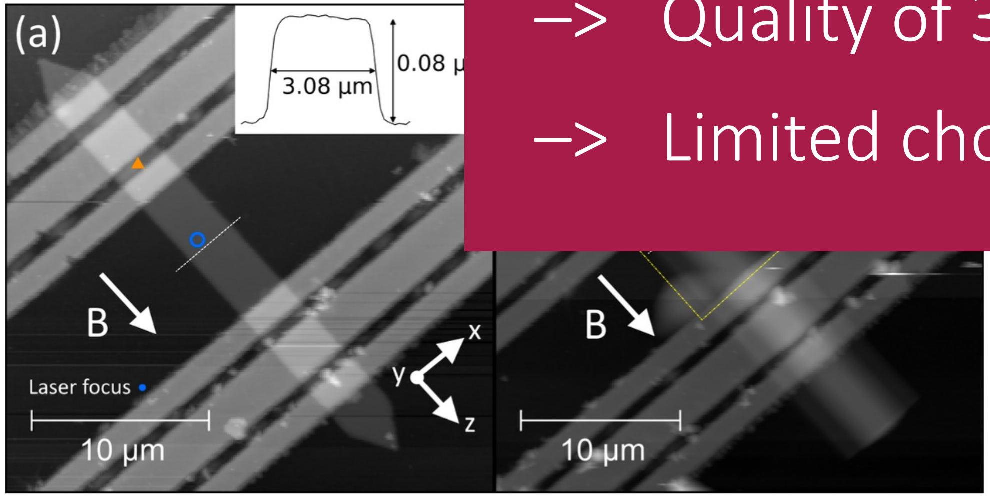
Mode profiles in nanovolcanoes

nanomaterials MDPI

Article

3D Magnonic Conduits by I

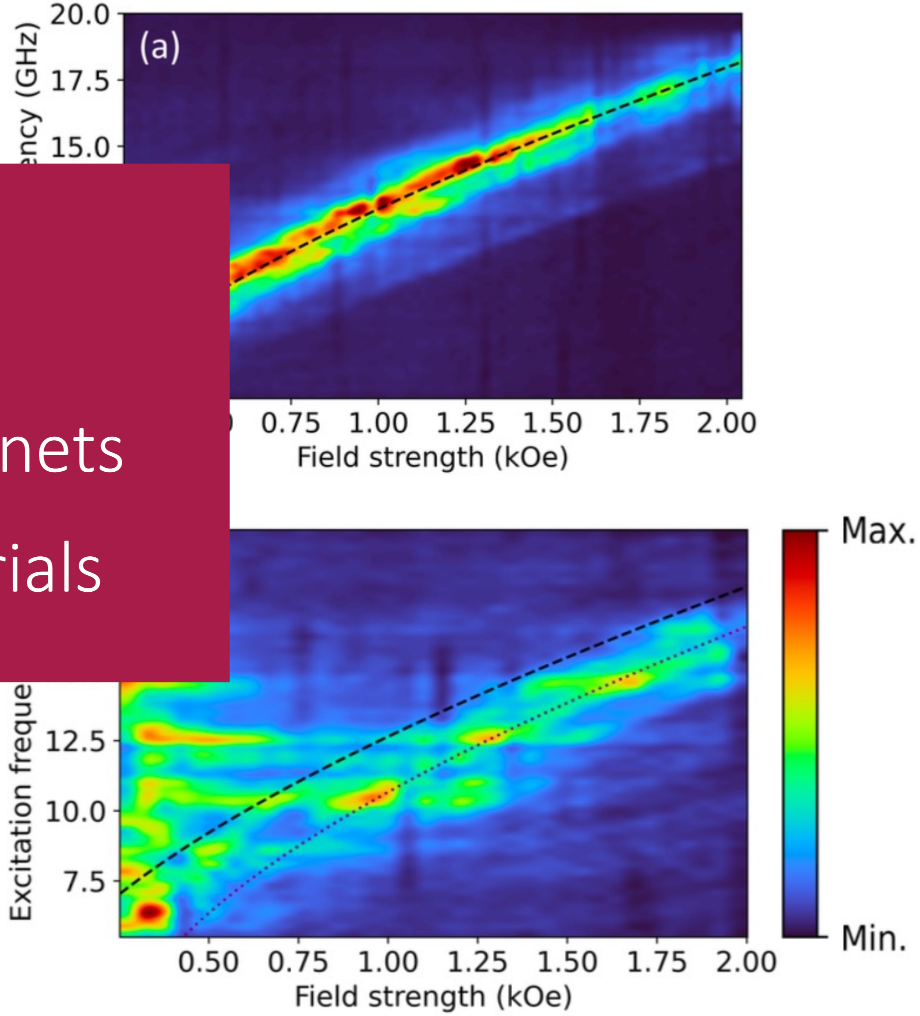
Sebastian Lamb-Camarena [1,2,*], Fabrizio Porrati
Sven Barth [3], Denys Makarov [6], Michael Huth



Challenges:

–> Quality of 3D Nanomagnets

–> Limited choice of materials



Lamb-Camarena, et al., Nanomaterials 13(13), 1926 (2023)

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Nanomagnetism and Magnonics

1st row: **Noura Zenbaa**, Andrii Chumak, Qi Wang, Oleksandr Dobrovolskiy, Barbora Budinská;
2nd row: Rostyslav Serha, Andrey Voronov, Khrystyna Levchenko, Fabian Majcen, Sebastian Lamb-Camarena, Pedro del Real;
3rd row: Richard Emberger, Sebastian Knauer, Simon Peinhaupt, Clemens Schmid; 4th row: David Schmoll, Andreas Höfinger, Aram Sajdak

Nano-scaled directional coupler

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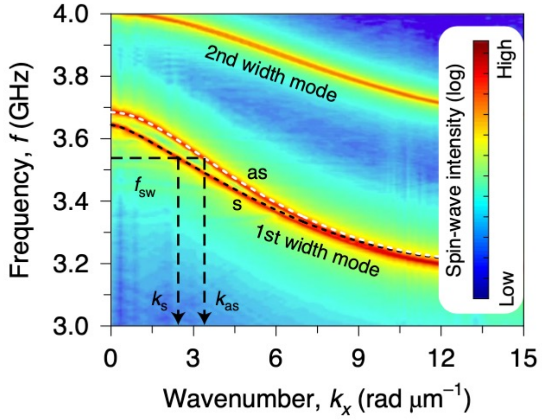
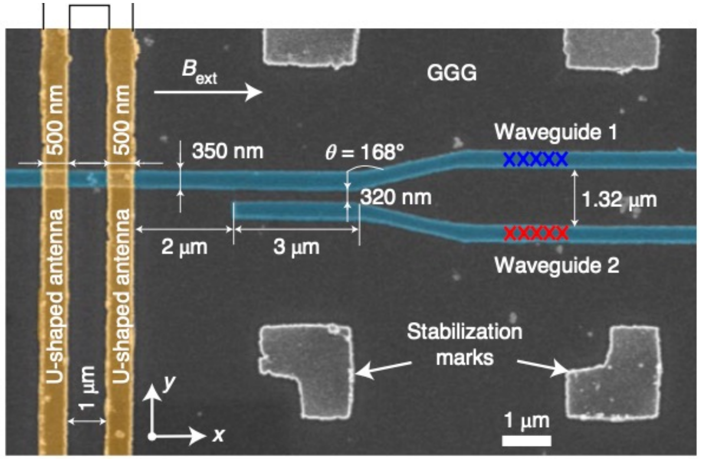
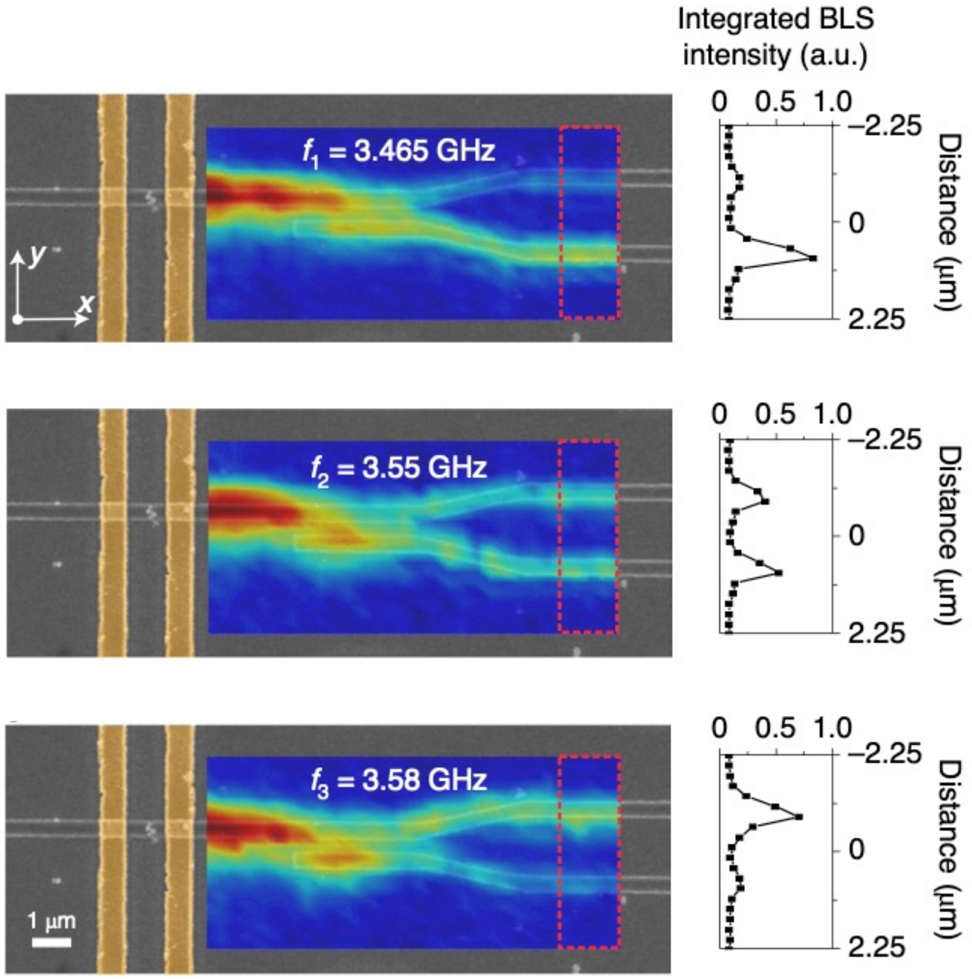
nature electronics
ARTICLES
https://doi.org/10.1038/s41928-020-00485-6
Check for updates

A magnonic directional coupler for integrated magnonic half-adders

Q. Wang[1,2], M. Kewenig[2], M. Schneider[2], R. Verba[3], F. Kohl[2], B. Heinz[2,4], M. Geilen[2], M. Mohseni[2], B. Lägel[5], F. Ciubotaru[6], C. Adelmann[6], C. Dubs[7], S. D. Cotofana[8], O. V. Dobrovolskiy[1], T. Brächer[2], P. Pirro[2] and A. V. Chumak[1,2]

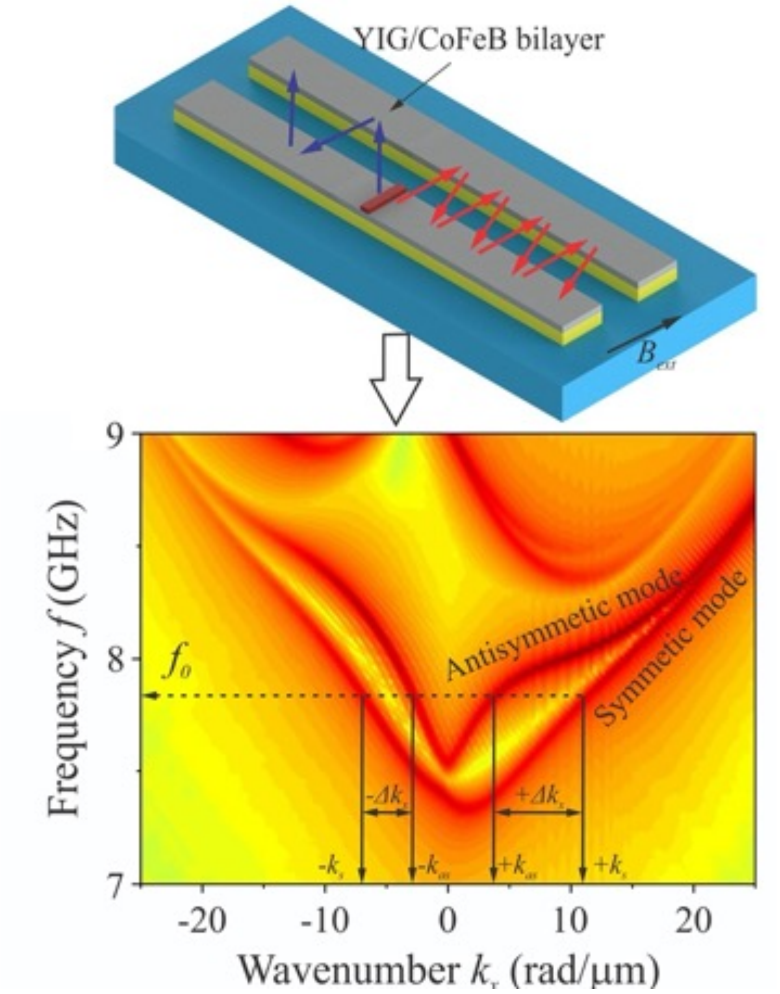




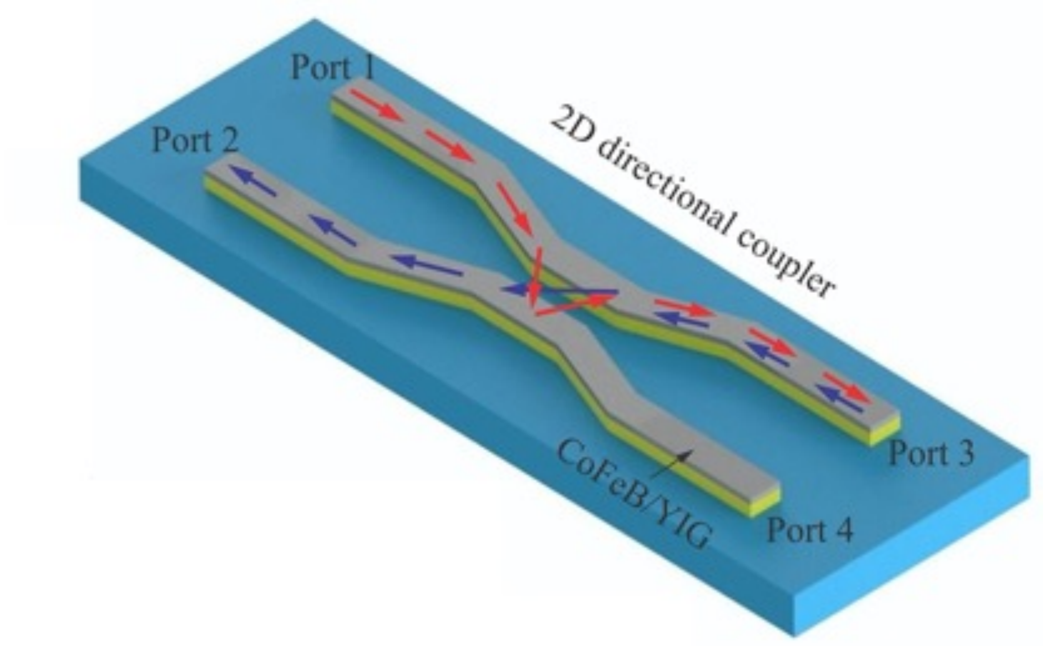


Wang, et al., Nature Electronics 3, 765 (2020)

Non-reciprocal magnonic directional coupler



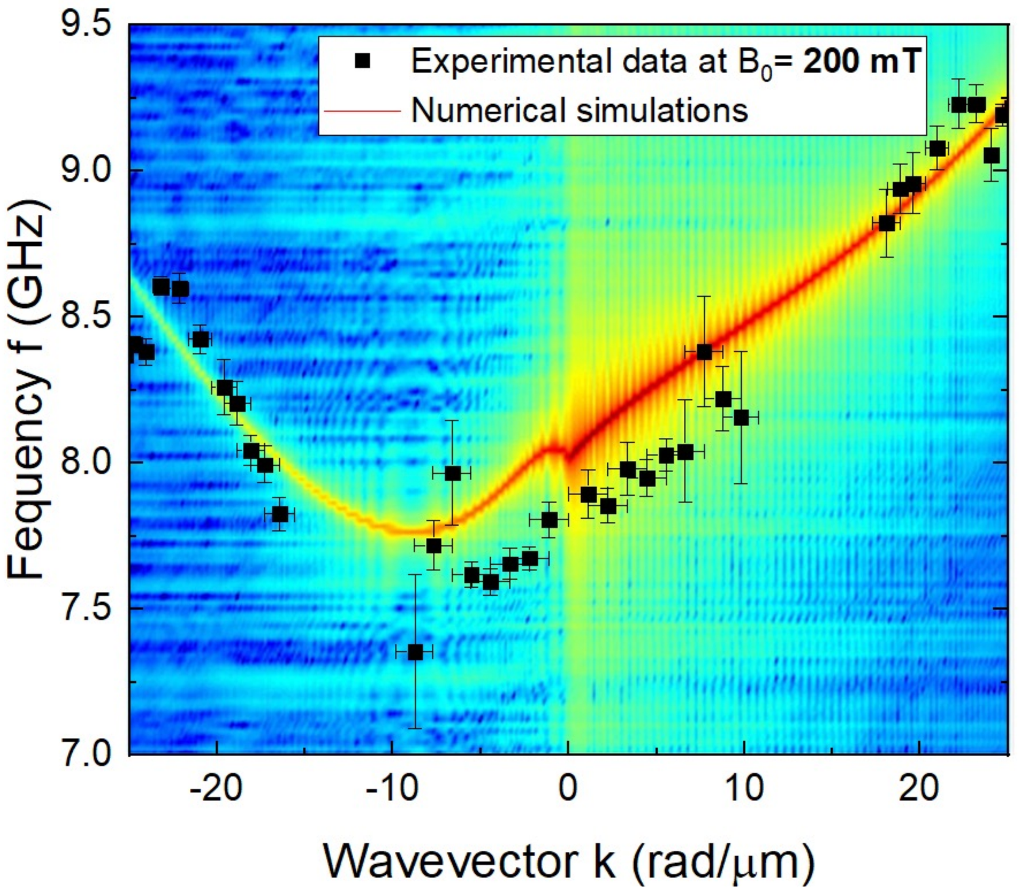
$$L = \frac{\pi}{\Delta k} = \frac{\pi}{|k_{as} - k_s|}, \quad L_{+k} \neq L_{-k}$$



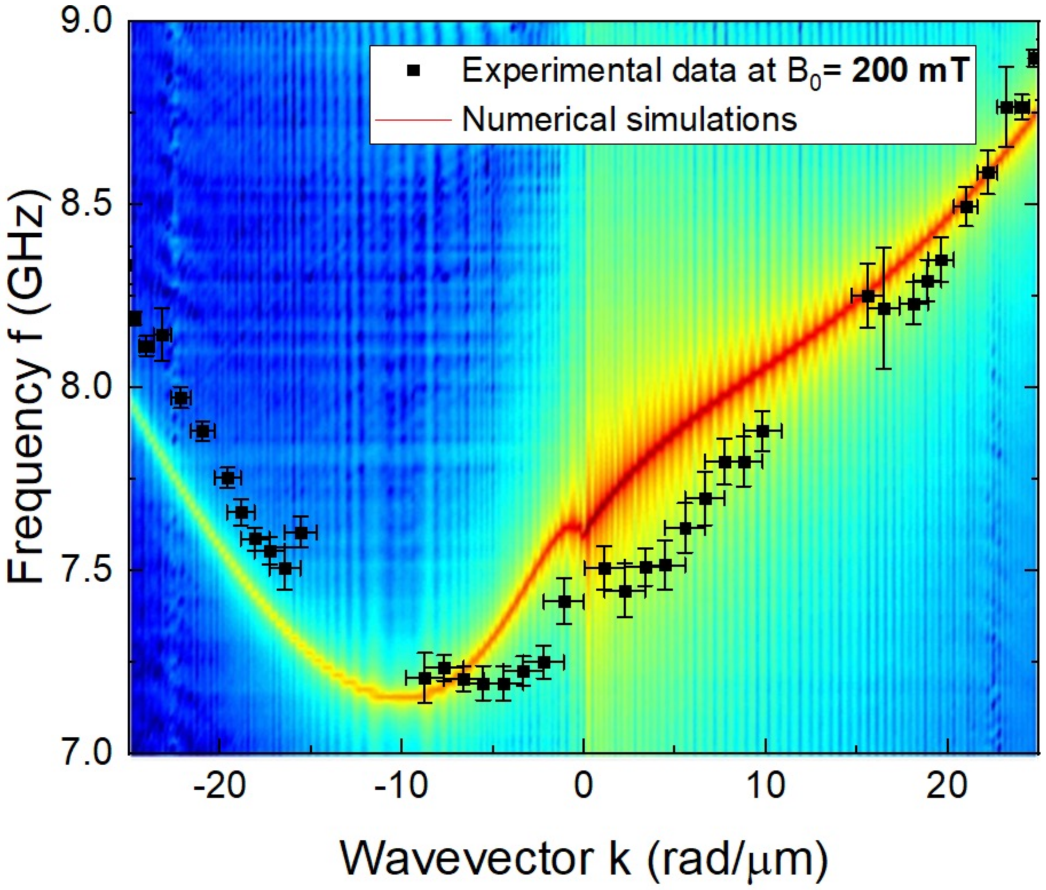
At a special frequency where $L_{-k} = 2 \times L_{+k}$

k-resolved BLS results

YIG(100)/CoFeB(40) film

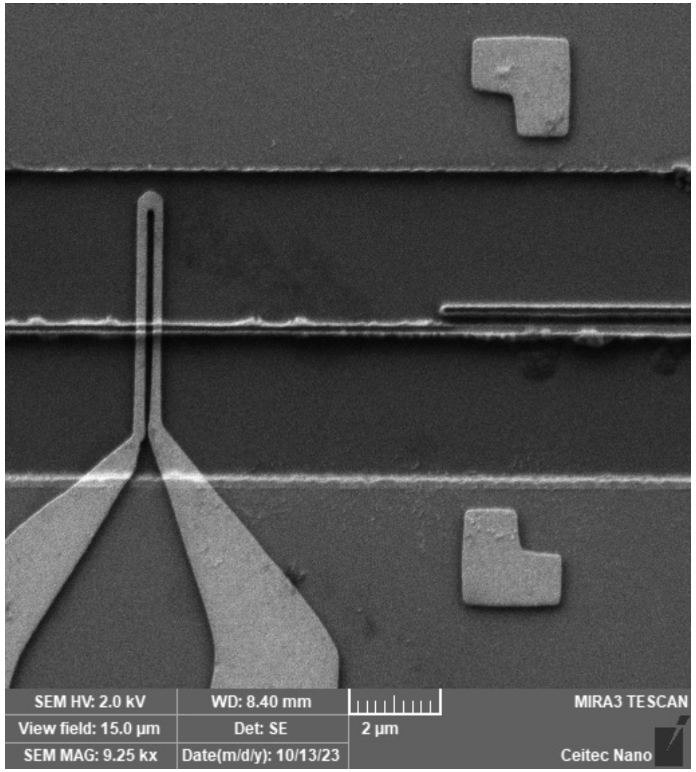


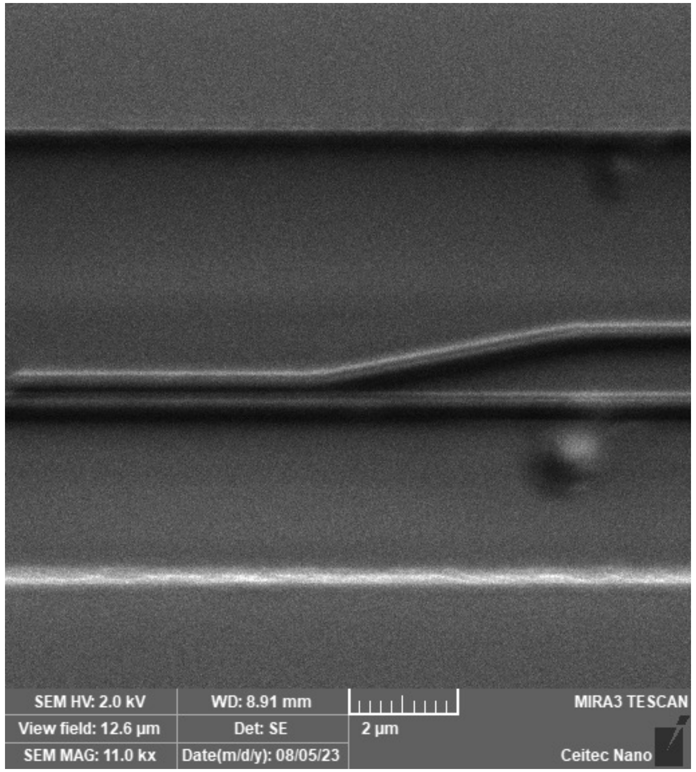
YIG(100)/SiO_2(5)/CoFeB(40) film

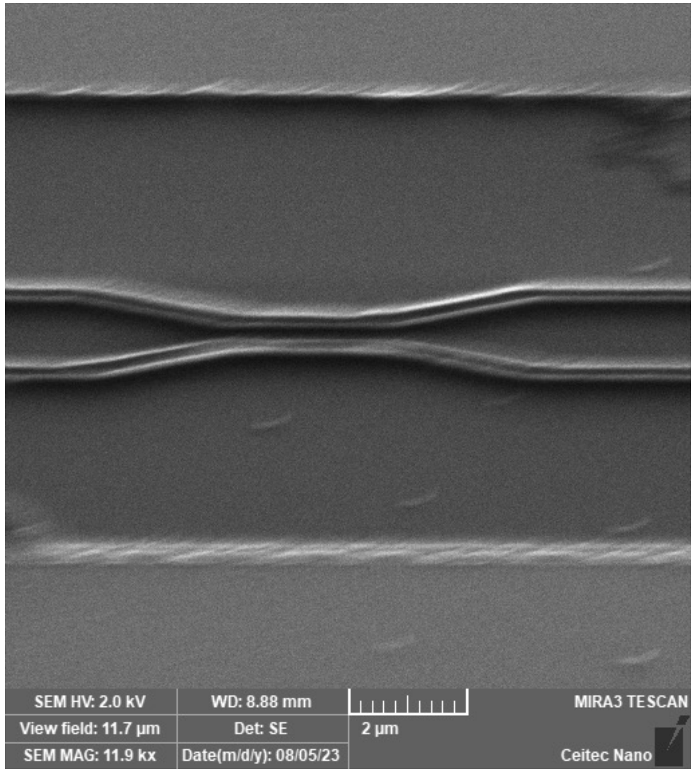


Fabrication of the non-reciprocal coupler

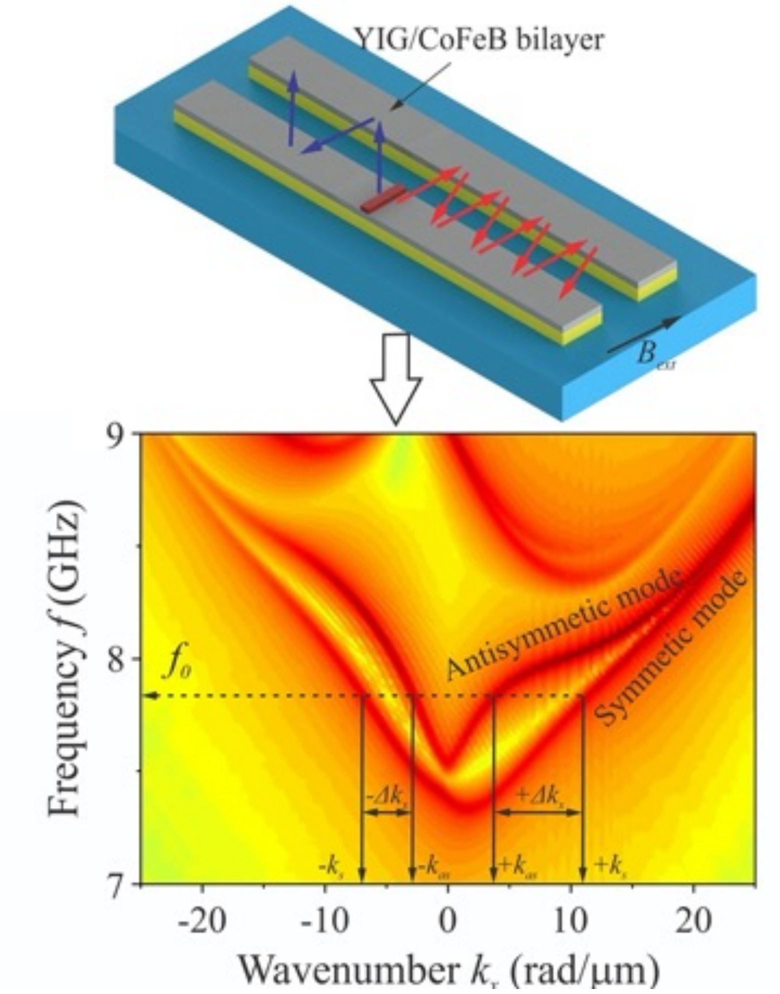
Sample: YIG(100nm)/NM(5nmm)/CoFeB(40nm)





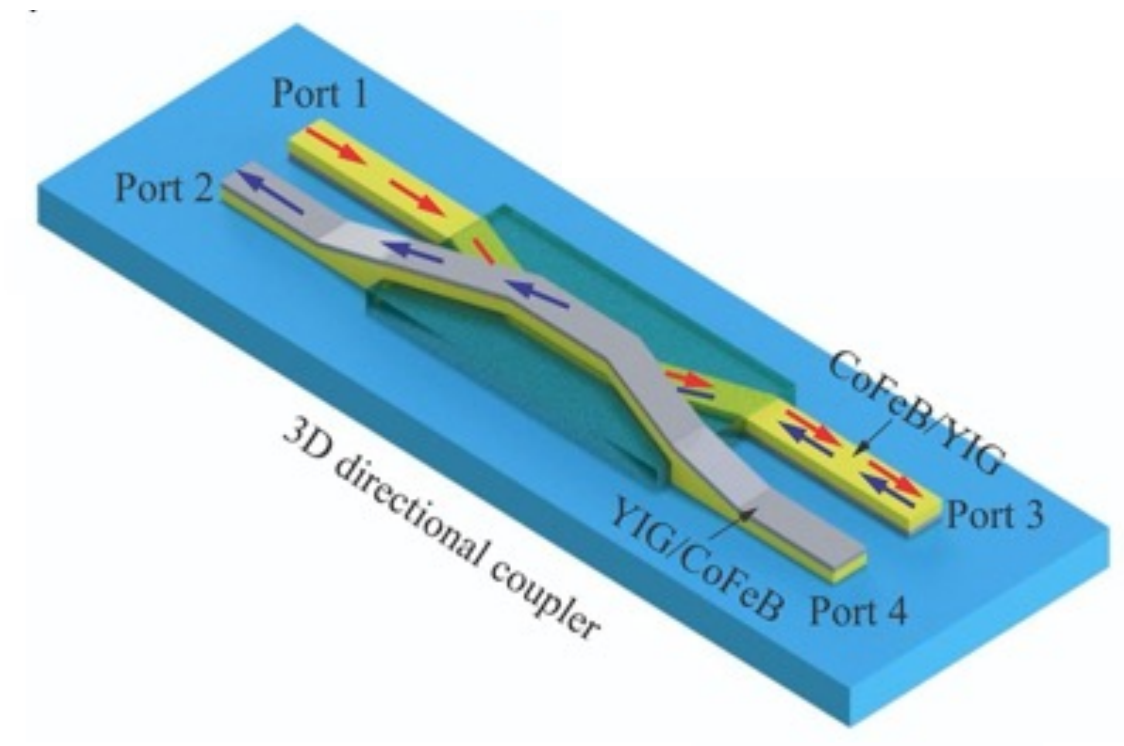


3D magnonic directional coupler



$$L = \frac{\pi}{\Delta k} = \frac{\pi}{|k_{as} - k_s|}, \quad L_{+k} \neq L_{-k}$$

Much stronger coupling!



At a special frequency where $L_{-k} = 2 \times L_{+k}$

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Bulk and Surface Modes in 3D Nanomagnonic Networks

RESEARCH ARTICLE

ADVANCED MATERIALS
www.advmat.de

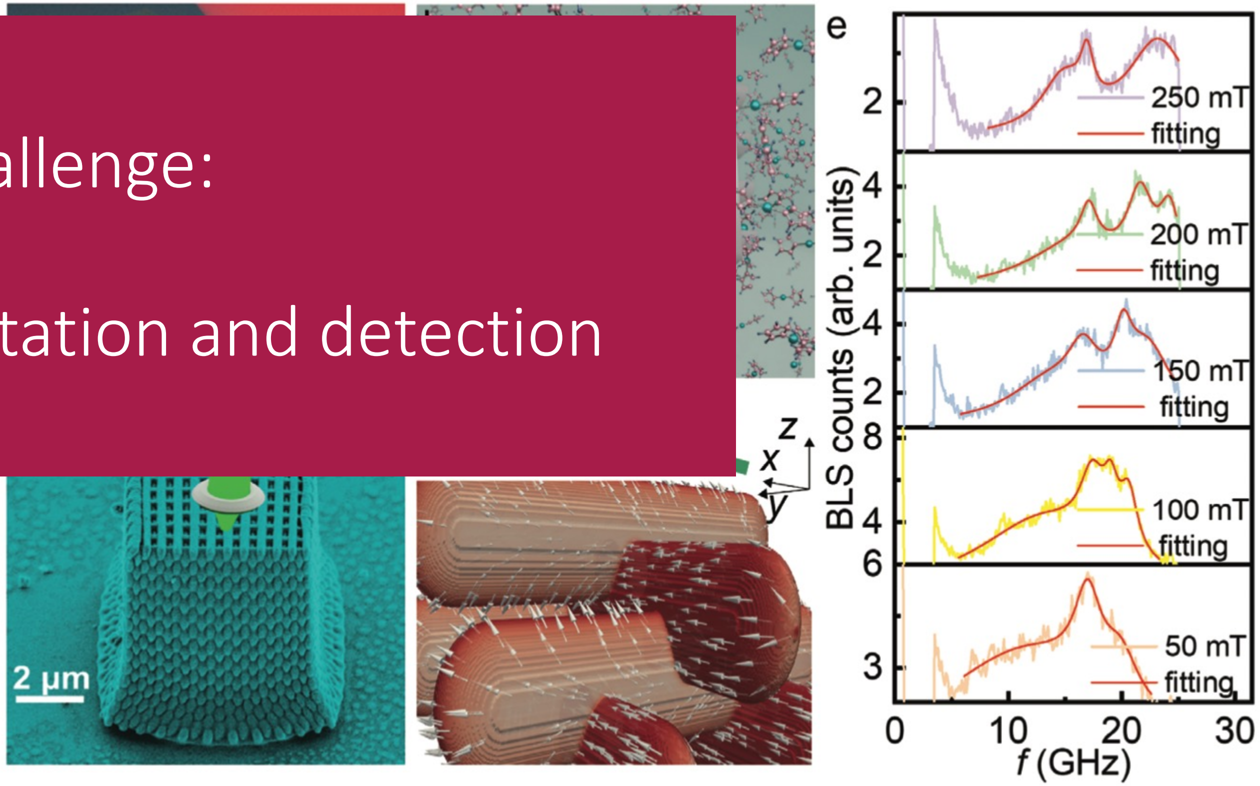
Realization and Control of Bulk and Surface Modes in 3D Nanomagnonic Networks b[…] Ferromagnets

Huixin Guo, Axel J. M. Deenen, Mingran […]

Adv. Mater. **2023**, 35, 2303292

Challenge:

–> Spin-wave excitation and detection



- two-photon-lithography (TPL)
- 3D nanonetworks conformally coated with a Ni shell
- plasma-enhanced ALD
- BLS measuremetns of thermal spectrum

Spin-wave dynamics in gyroid nanostructures

ACS APPLIED MATERIALS & INTERFACES

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www.acsami.org

Research Article

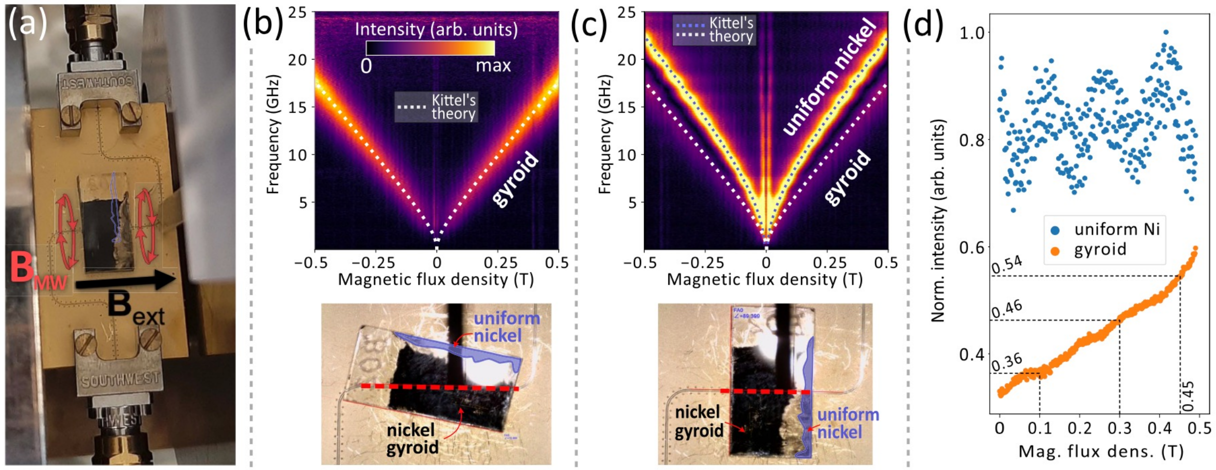
Collective Spin-Wave Dynamics in Gyroid Ferromagnetic Nanostructures

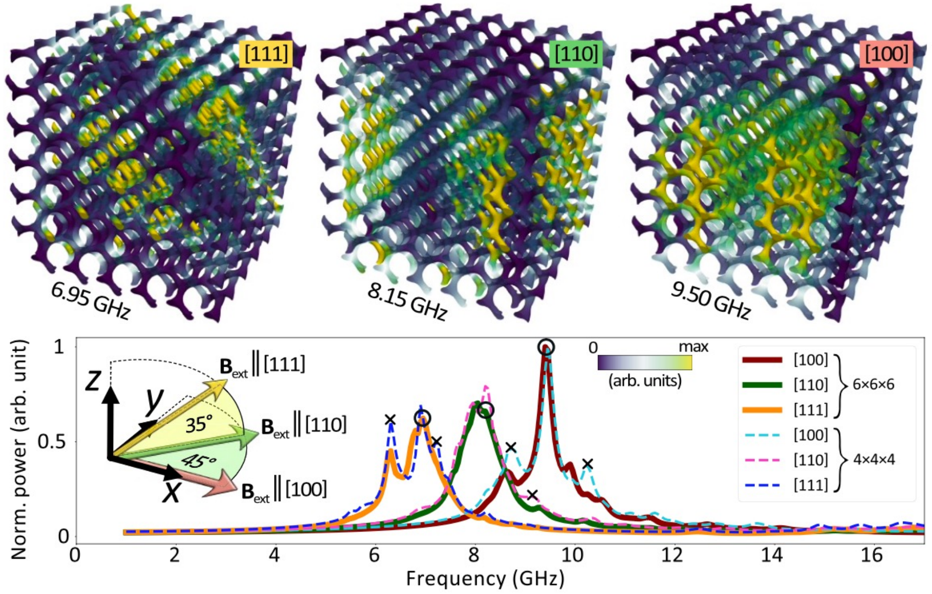
Mateusz Gołębiewski,* Riccardo Hertel, Massimiliano d'Aquino, Vitaliy Vasyuchka, Mathias Weiler, Philipp Pirro, Maciej Krawczyk, Shunsuke Fukami, Hideo Ohno, and Justin Llandro

Cite This: *ACS Appl. Mater. Interfaces* 2024, 16, 22177–22188

Read Online

- unit cell of the investigated gyroid sample measures 50 nm
- volume fraction of approximately 10% (4 nm node)
- block copolimer
- micromagnetics and FMR





Coherent spin waves in a 3D ASI

NANO LETTERS

pubs.acs.org/NanoLett

Observation of Coherent Spin W
Artificial Spin Ice Structure

Sourav Sahoo, Andrew May, Arjen van Den Berg,

Cite This: *Nano Lett.* 2021, 21, 4629–4635

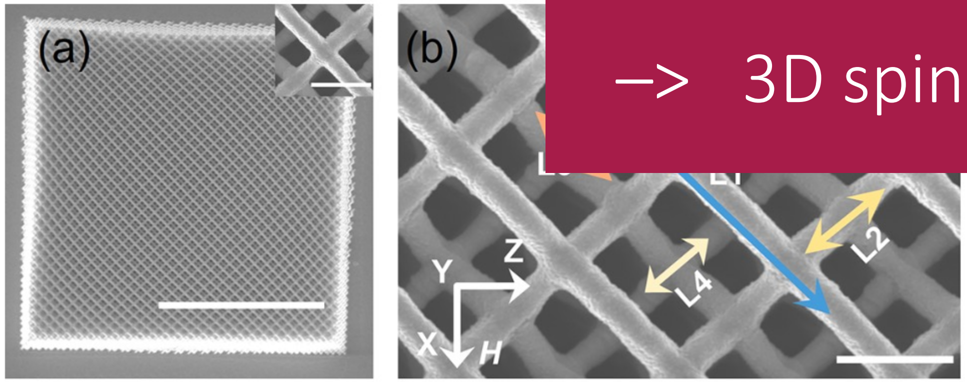
- two-photon-lithography (TPL) + thermal evaporation
  Fe_{19}
- ns of coherent magnons

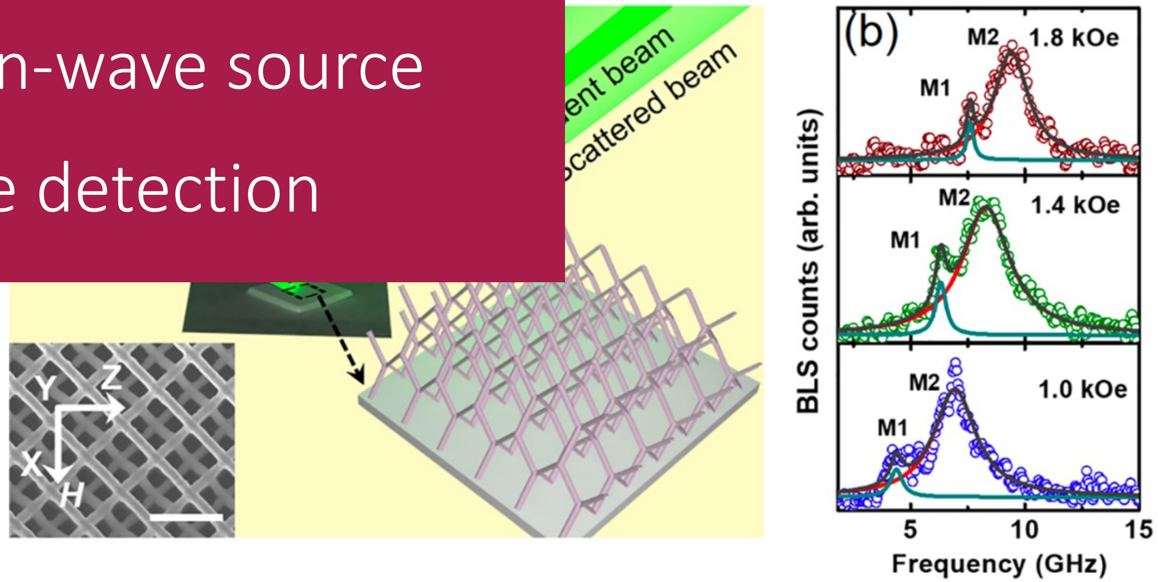
Challenge:

–> Shadowing effect

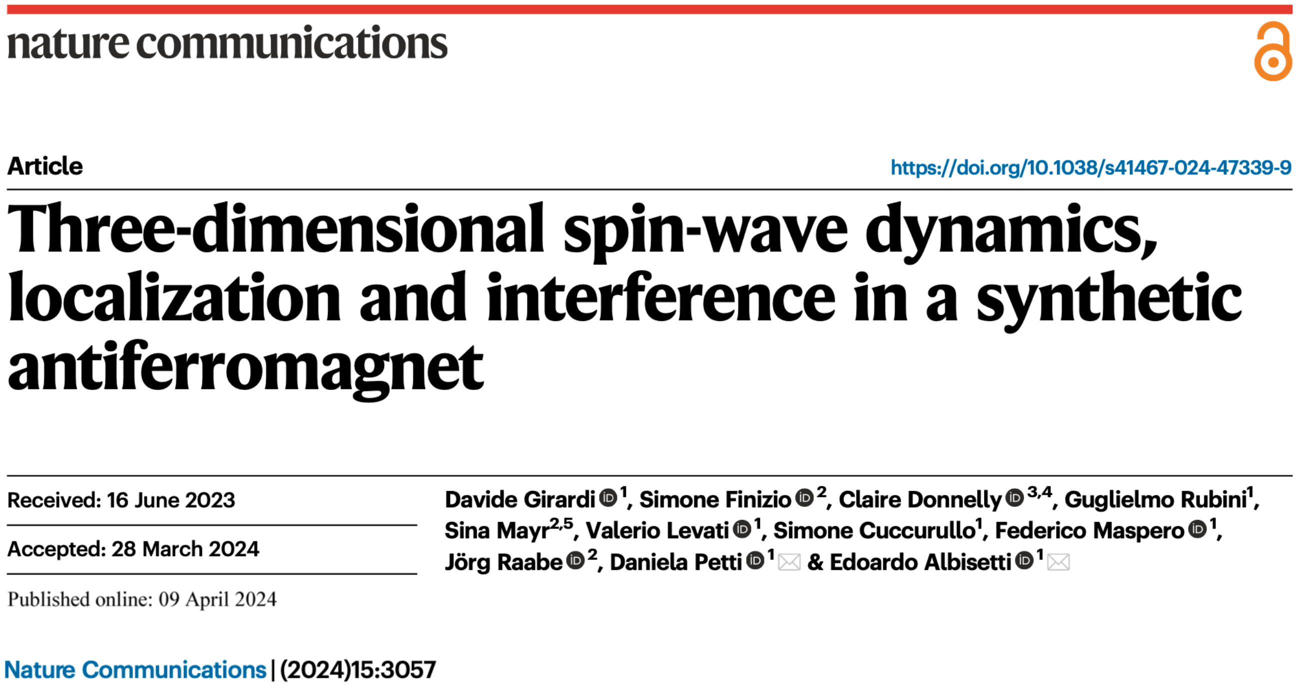
–> Localised spin-wave source

–> 3D spin-wave detection





3D spin-wave mapping



nature communications

Article

https://doi.org/10.1038/s41467-024-47339-9

Three-dimensional spin-wave dynamics, localization and interference in a synthetic antiferromagnet

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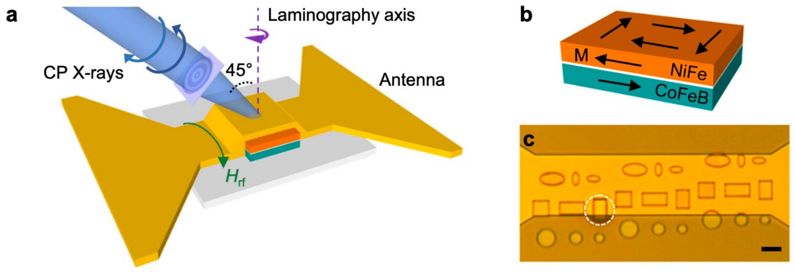
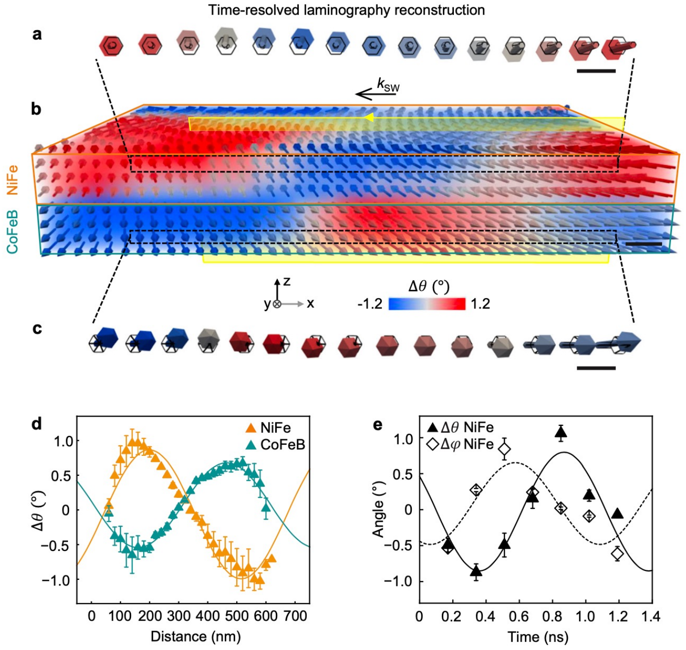
Davide Girardi[1], Simone Finizio[2], Claire Donnelly[3,4], Guglielmo Rubini[1], Sina Mayr[2,5], Valerio Levati[1], Simone Cuccurullo[1], Federico Maspero[1], Jörg Raabe[2], Daniela Petti[1] & Edoardo Albisetti[1]

Nature Communications | (2024)15:3057





- SAF: CoFeB 50 / Ru 0.5 / NiFe 40 / Ru 4 (nm)
- time-resolved magnetic laminography
- the full 3D landscape of coherent propagating spin waves was reconstructed

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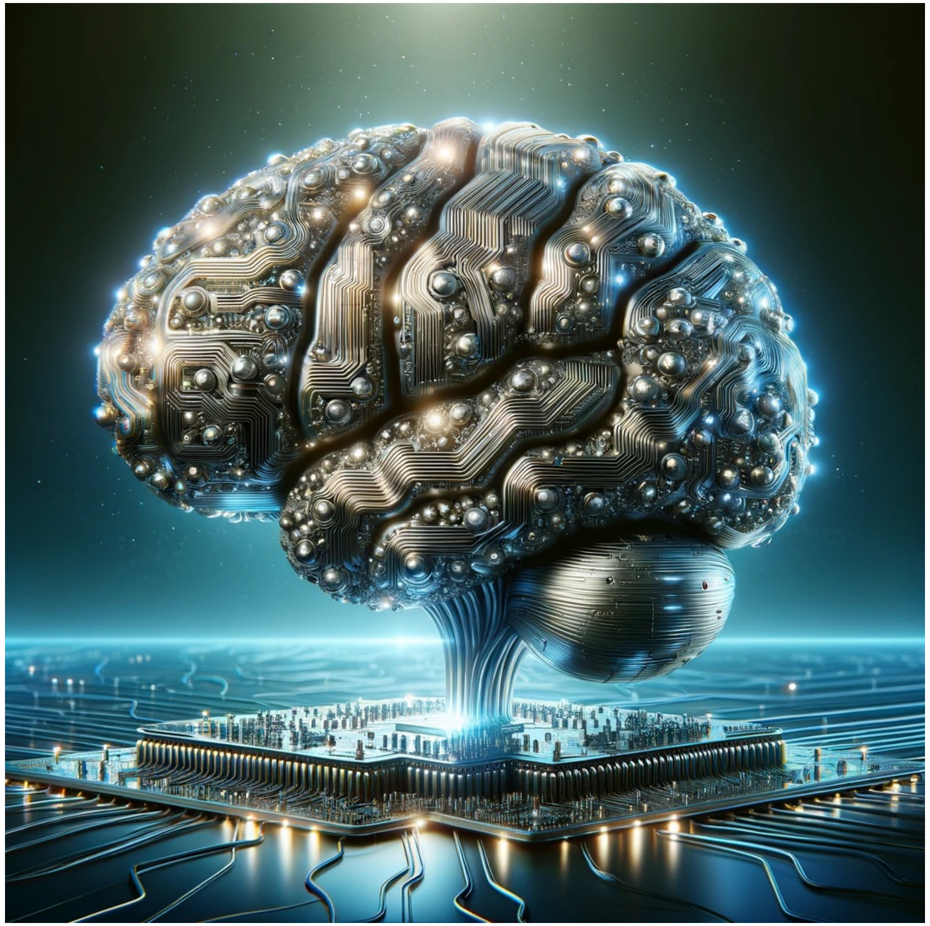
3D magnonics

High quantity of elements + new physics

Inverse-design magnonics

Any type of computing, incl. neuromorphic



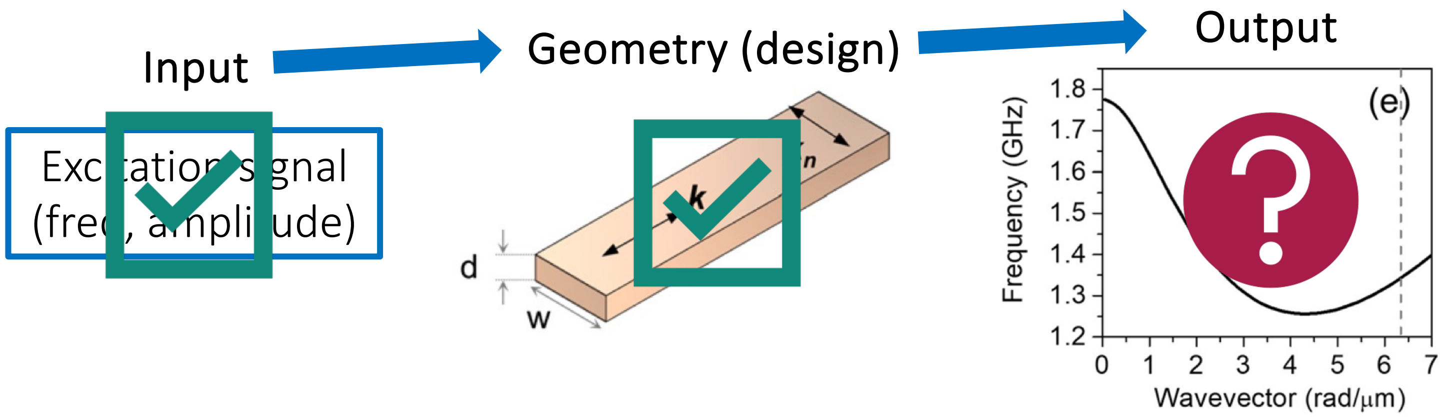
ChatGPT4:
“magnonic computer that looks like a human brain”

Nanomagnetism and Magnonics

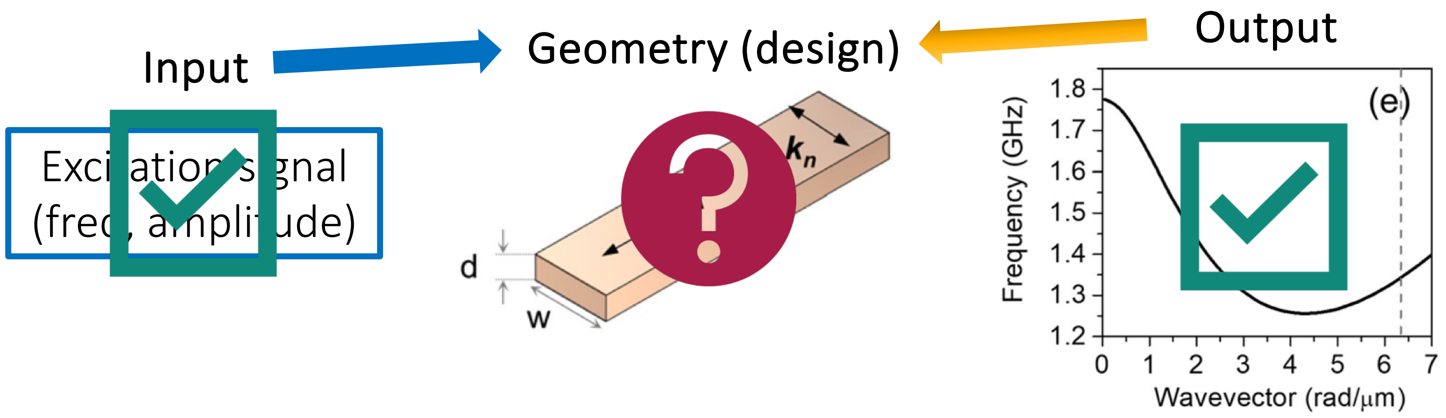
1st row: **Noura Zenbaa**, Andrii Chumak, **Qi Wang**, Oleksandr Dobrovolskiy, Barbora Budinská;
2nd row: Rostyslav Serha, **Andrey Voronov**, Khrystyna Levchenko, **Fabian Majcen**, Sebastian Lamb-Camarena, Pedro del Real;
3rd row: Richard Emberger, Sebastian Knauer, Simon Peinhaupt, Clemens Schmid; 4th row: David Schmoll, Andreas Höfinger, Aram Sajdak

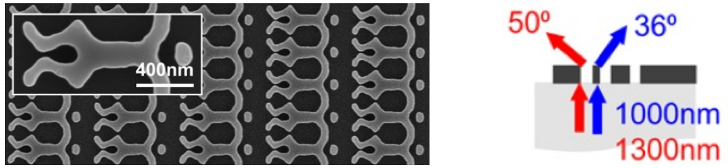
Inverse-design concept

Conventional experiment (direct design)

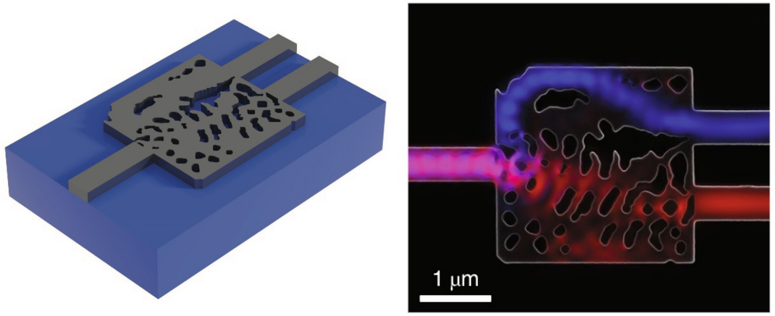


Inverse design

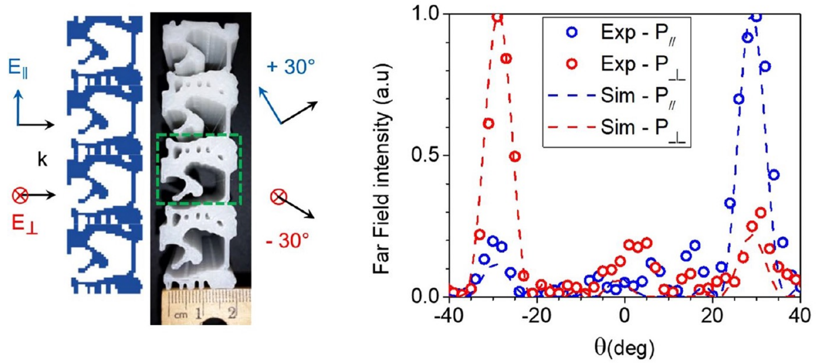




D. Sell, *et al*. *Nano letters* **17**, 3752, 2017

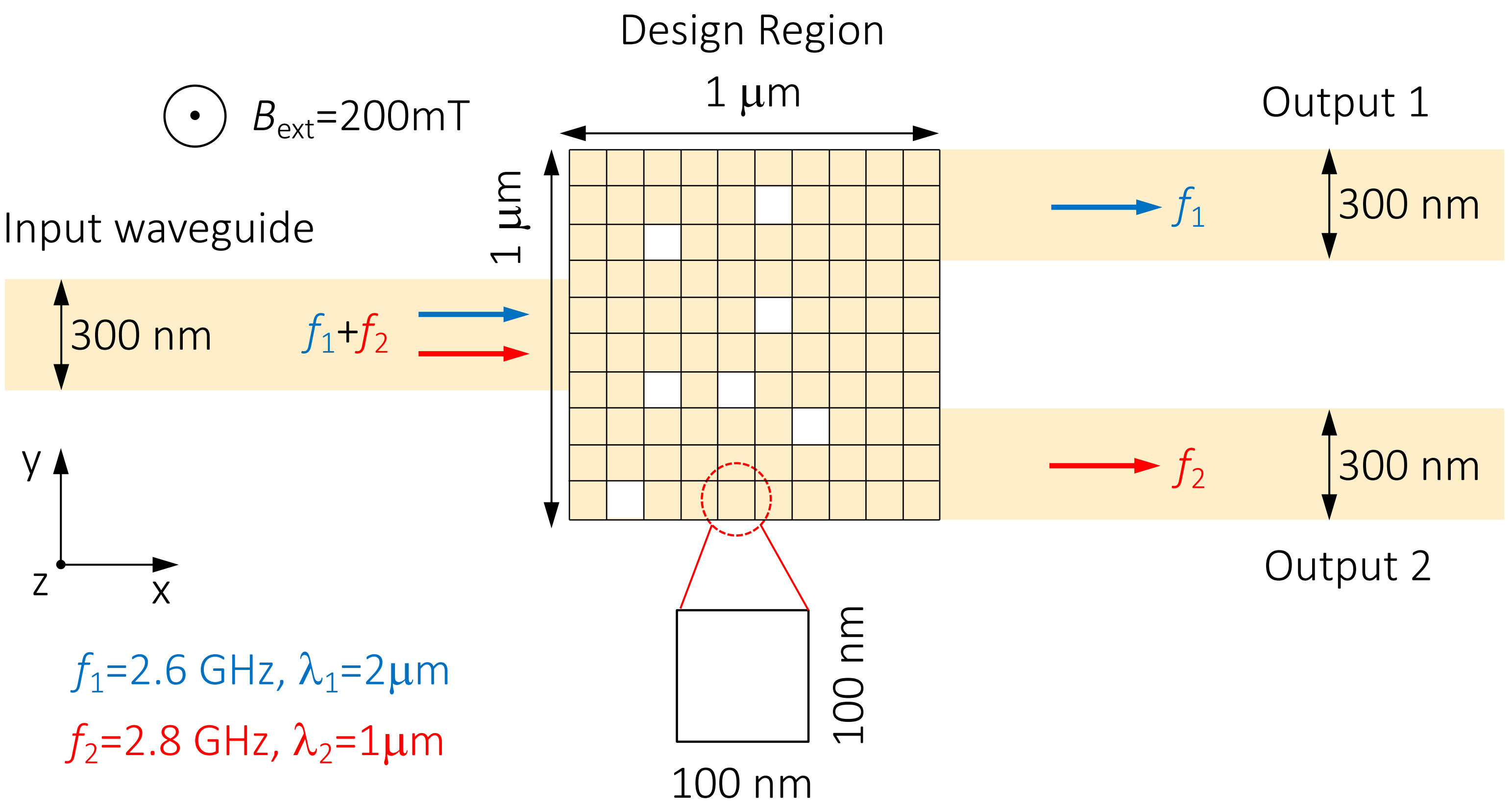


A. Piggott, *et al*. *Nature Photonics* **9**, 374, 2015



F. Callewaert, *et al*. *Scientific reports* **8**, 1, 2018

Magnonic demultiplexer



f_1=2.6 GHz, λ_1=2μm

f_2=2.8 GHz, λ_2=1μm

Yttrium Iron Garnet (YIG):

M_s = 1.4×10^5 A/m

A = 3.5 pJ/m

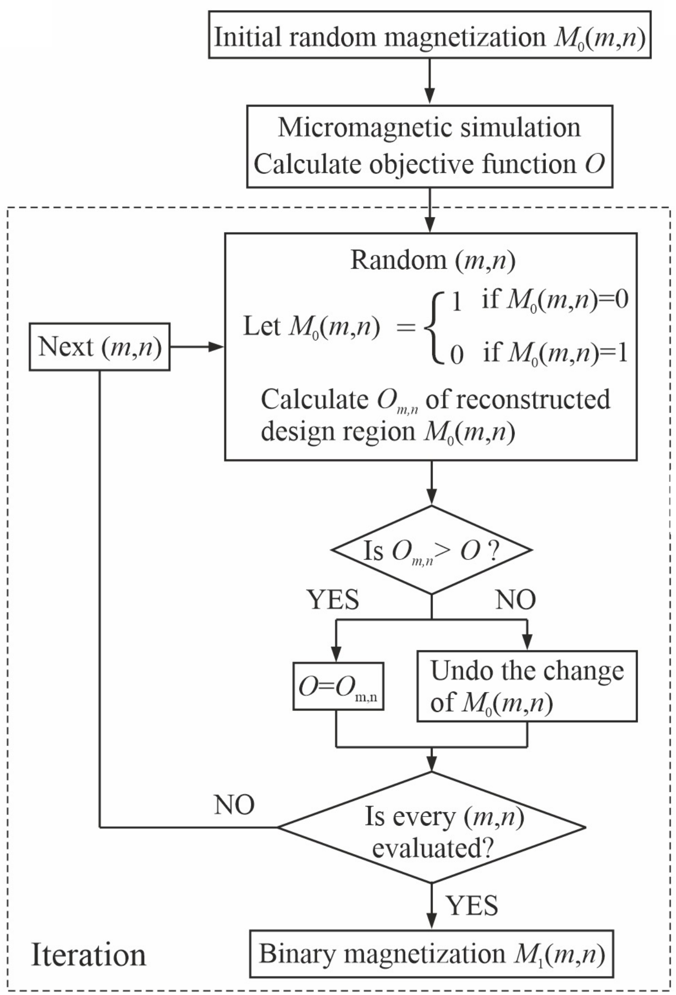
α = 2×10^{-4}

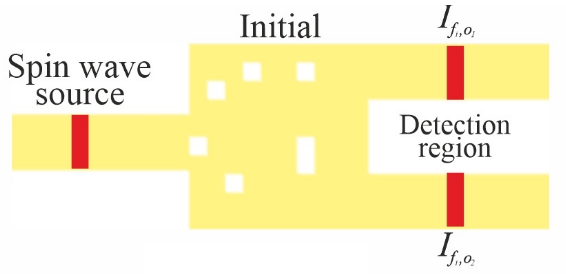
thickness = 100 nm

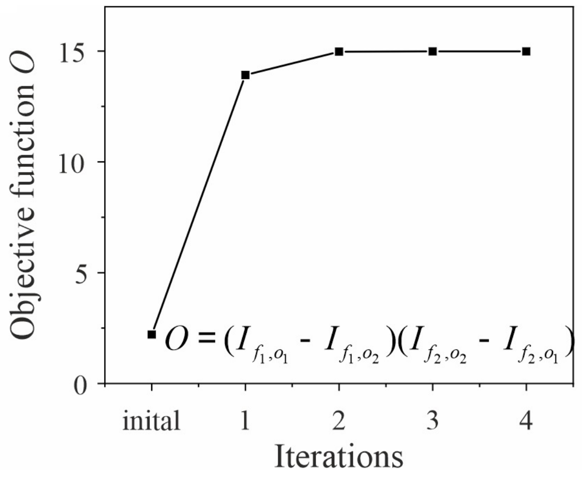
Cell size: 20 nm

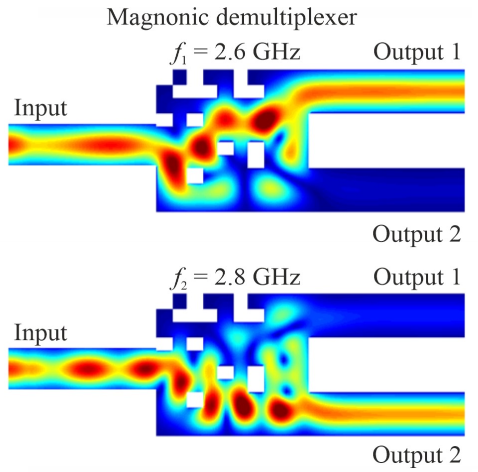
Wang, Chumak, Pirro, Nature Commun., 12, 2636 (2021)

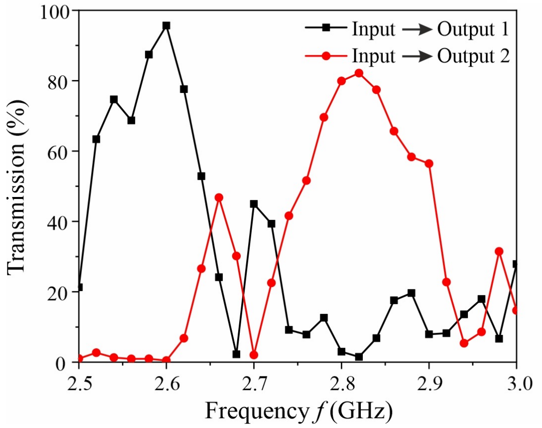
Inverse design algorithm





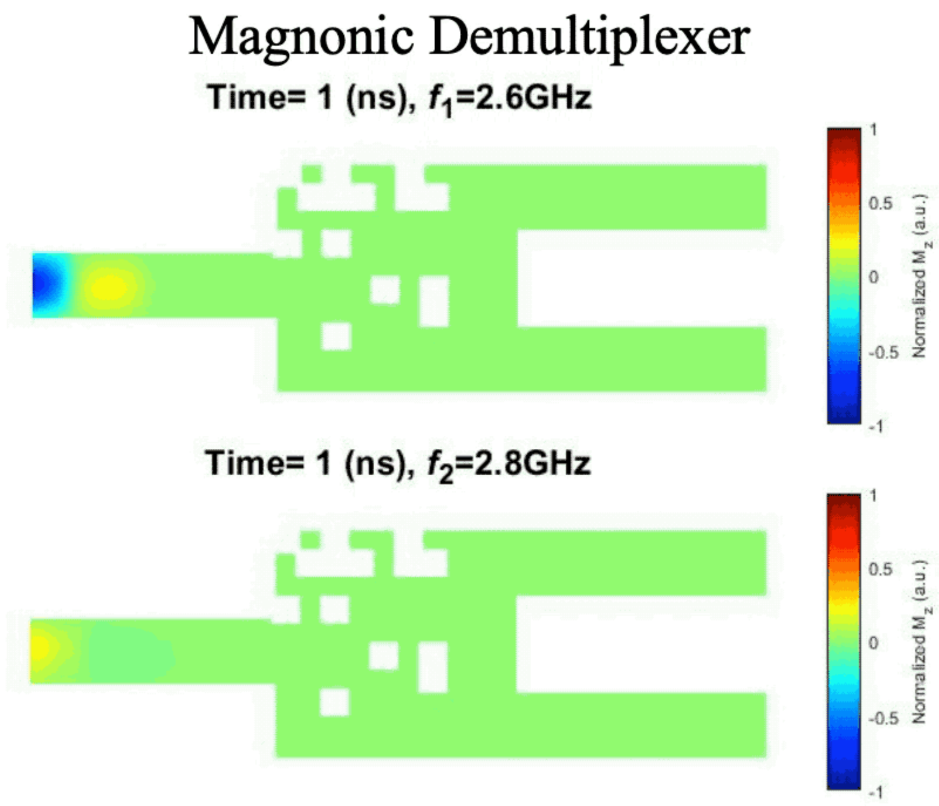


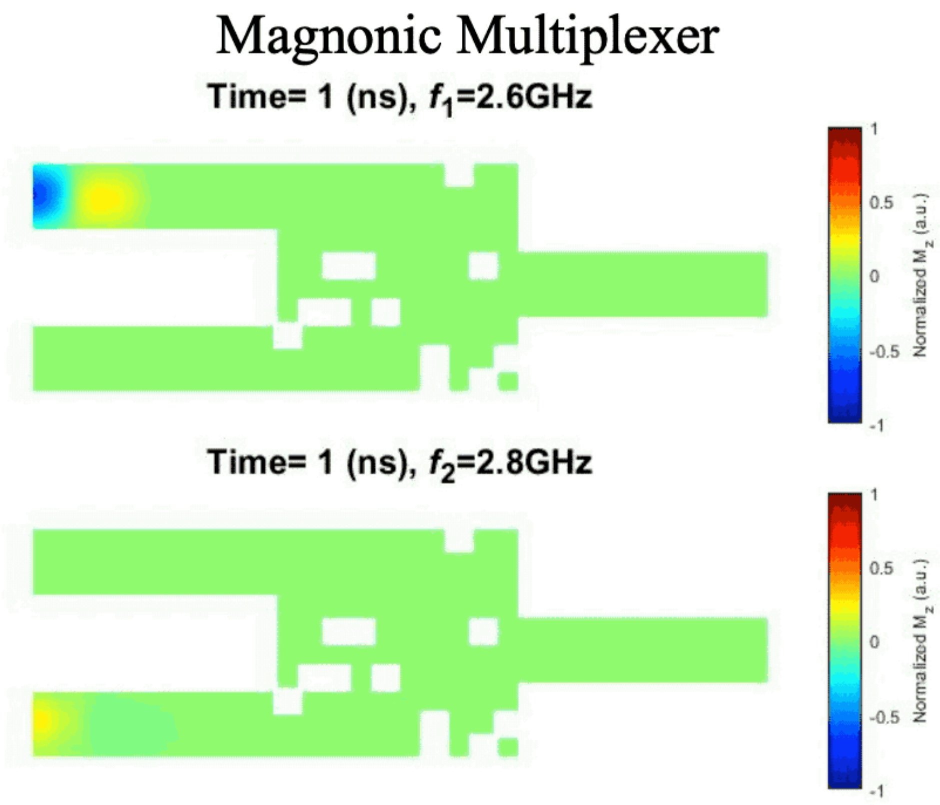




Wang, Chumak, Pirro, Nature Commun., 12, 2636 (2021)

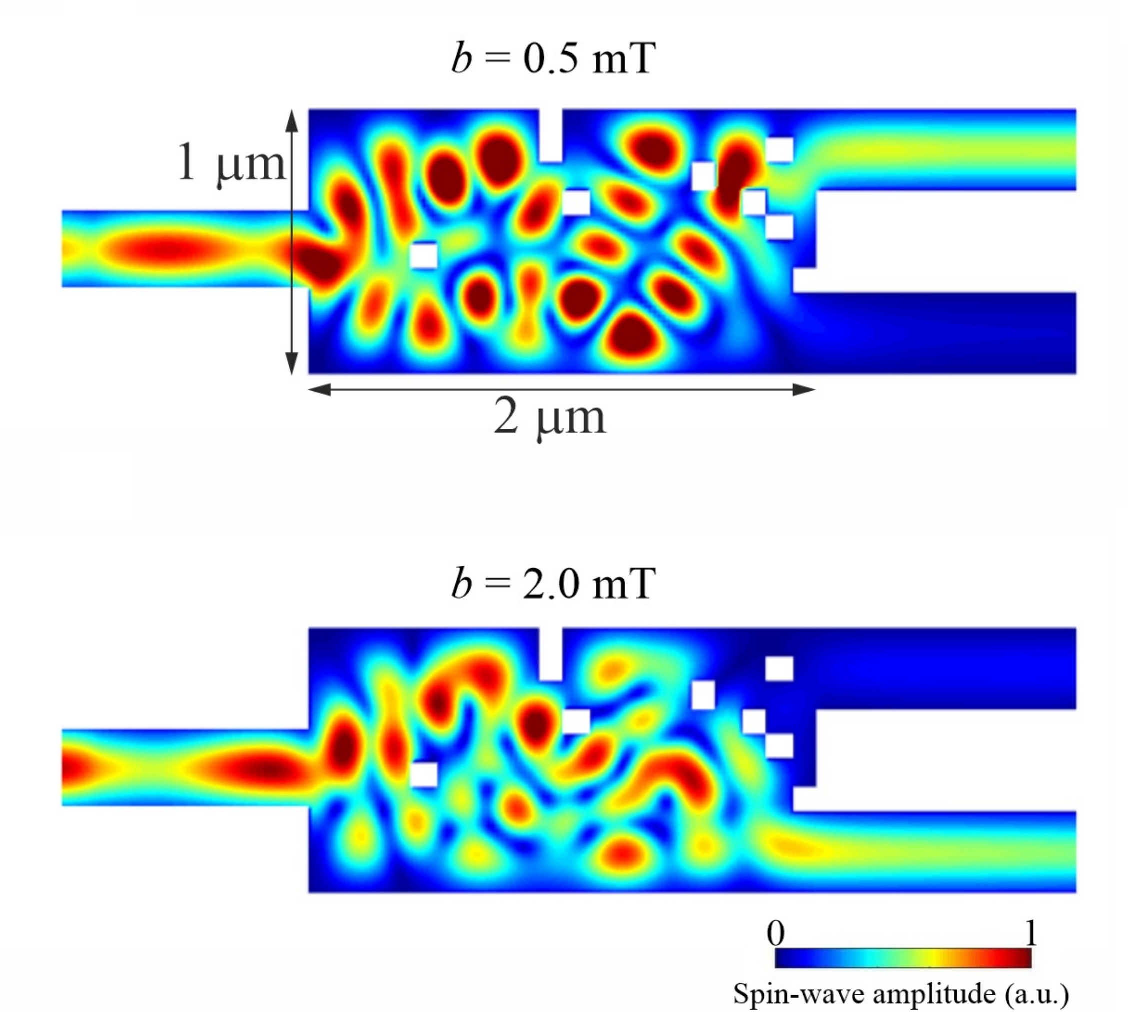
Inverse-design (de-)multiplexer

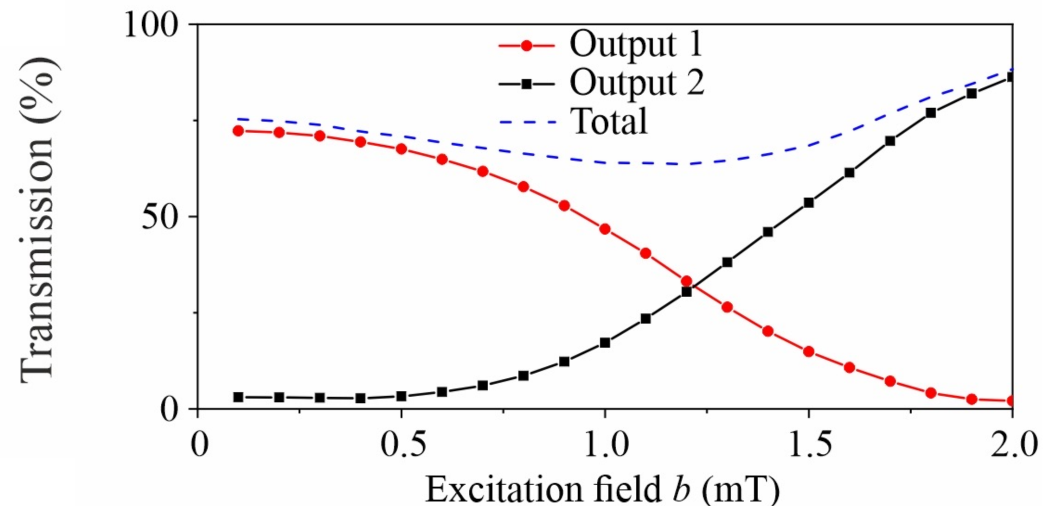




Wang, Chumak, Pirro, Nature Commun., 12, 2636 (2021)

Nonlinear spin-wave switch

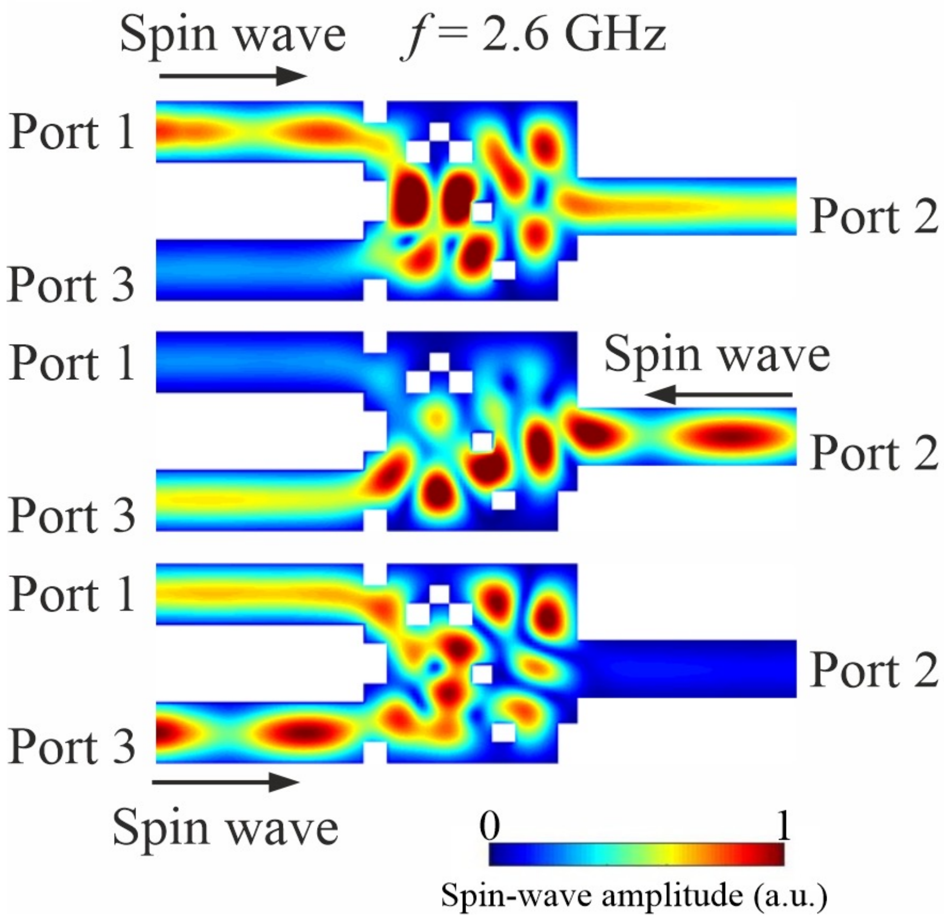




Inverse-designed nonlinear spin-wave switch works!

Wang, Chumak, Pirro, Nature Commun., 12, 2636 (2021)

Nonreciprocal magnonic circulator



Advantages compared to inverse-design photonics

1) Scalability
(10 nm was shown)
2) Pronounced nonlinearity
3) Natural nonreciprocity

Wang, Chumak, Pirro, Nature Commun., 12, 2636 (2021)

Nanoscale neural network using non-linear spin-wave interference

nature COMMUNICATIONS

ARTICLE

Check for updates

https://doi.org/10.1038/s41467-021-26711-z

OPEN

Nanoscale neural network using non-linear spin-wave interference

Ádám Papp[1], Wolfgang Porod[2] & Gyorgy Csaba[1✉]

NATURE COMMUNICATIONS | (2021)12:6422 | https://doi.org/10.1038/s41467-021-26711-z | www.nature.com/naturecommunications

Nanoscale neural network using non-linear spin-wave interference

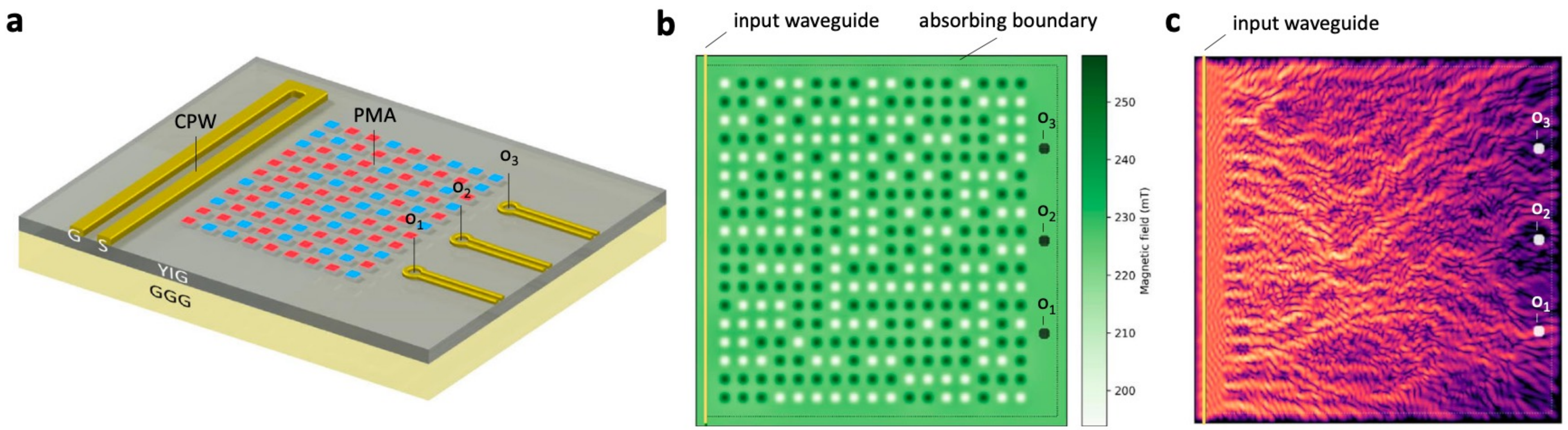
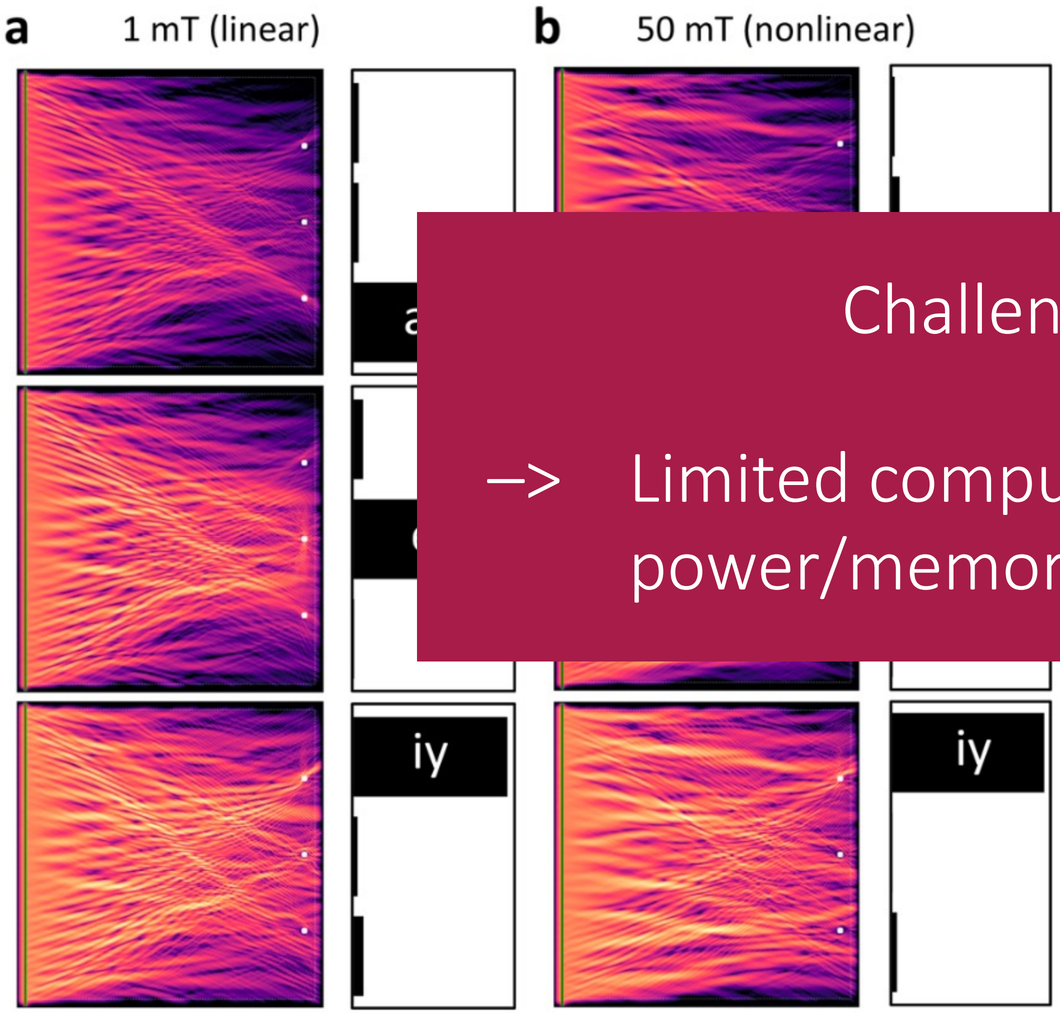


Fig. 1 Nanomagnet-based spin-wave scatterer. a The schematics of the envisioned computing device. The input signal is applied on the coplanar waveguide (CPW) on the left and the magnetic state (up/down) of programming magnets on top of the YIG film define the weights. **b** Magnets exhibiting perpendicular magnetic anisotropy are placed on top of the YIG film and generate a bias-field landscape. The training algorithm finds the binary state of the programming magnets. **c** Spin-wave intensity pattern for a particular applied input, which results in a high intensity at o_1. The size of the simulation area is 10 μm × 10 μm.

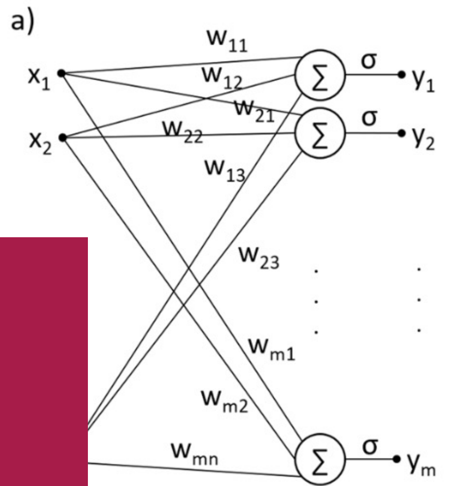
Papp, Porod, Csaba, Nature Commun., 12, 6422 (2021)

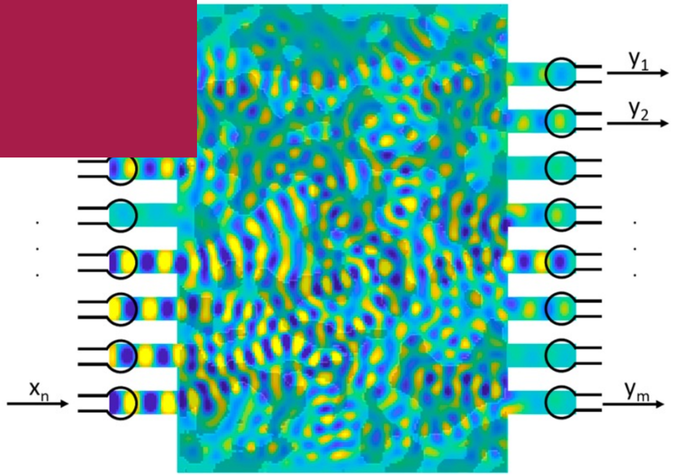
Nanoscale neural network using non-linear spin-wave interference



Challenge:

–> Limited computational power/memory





Papp, Porod, Csaba, Nature Commun., 12, 6422 (2021)

Experimental Demonstration of a Spin-Wave Lens Designed with Machine Learning

IEEE MAGNETICS LETTERS, Volume 13 (2022) 6105305

Nanomagnetics

Experimental Demonstration of a Spin-Wave Lens Designed With Machine Learning

Martina Kiechle[1*], Levente Maucha[2], Valentin Ahrens[1], Carsten Dubs[3], Wolfgang Porod[4], Gyorgy Csaba[2], Markus Becherer[1], and Adam Papp[2]

[1] *Department of Electrical and Computer Engineering, Technical University of Munich, 80809 Munich, Germany*
[2] *Faculty of Information Technology and Bionics, Pázmány Péter Catholic University, 1083 Budapest, Hungary*
[3] *INNOVENT e.V. Technologieentwicklung, 07745 Jena, Germany*
[4] *Department of Electrical Engineering, University of Notre Dame, Notre Dame, IN 46556, USA*
* *Graduate Student Member, IEEE*

Received 30 Jun 2022, revised 12 Aug 2022, accepted 24 Aug 2022, published 26 Sep 2022, current version 13 Oct 2022.

Experimental Demonstration of a Spin-Wave Lens Designed with Machine Learning

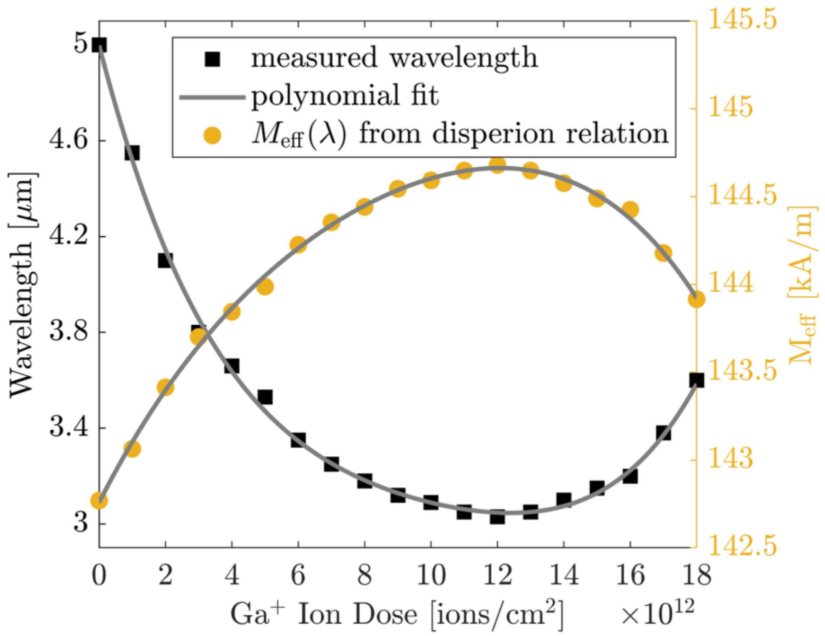
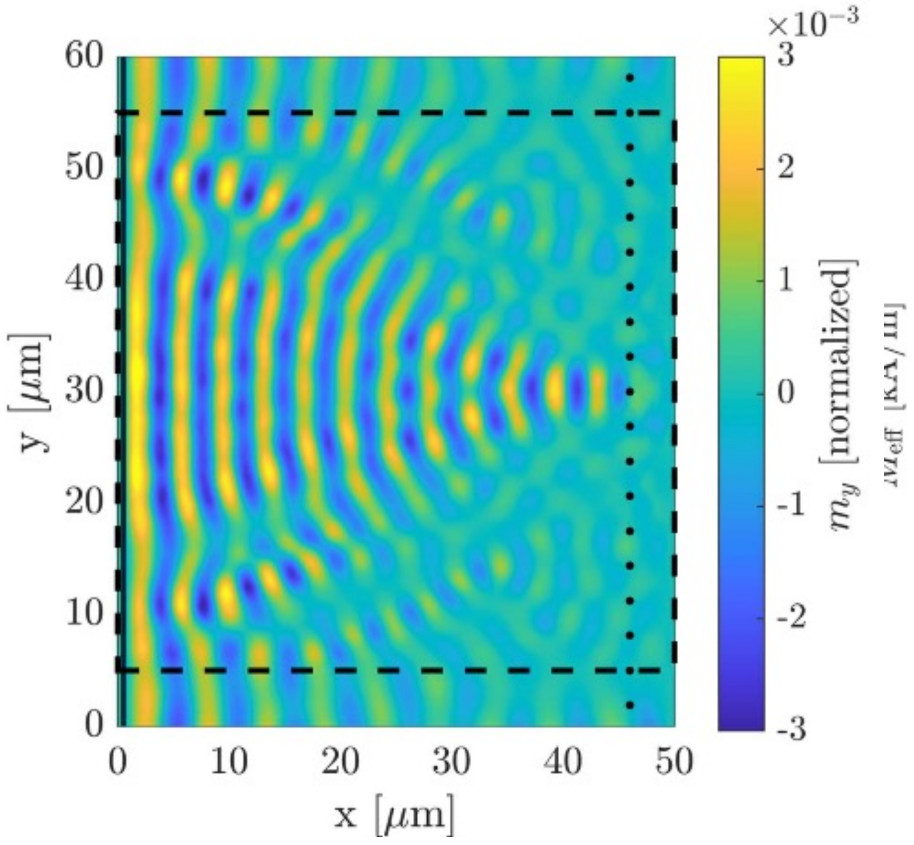


Fig. 1. Nonlinear trend of the ion-dose-dependent change in YIG. The modified wavelengths λ_{FIB} were measured in 38 × 38 μm regions irradiated with the respective ion dose. Subsequently, the effective magnetization change was calculated from the respective λ_{FIB} and the spin-wave dispersion relation. The largest M_{eff} = 144.7 kA/m is used as the basis for the training.



Kiechle, et al. IEEE Mag. Lett. 13, 6105305 (2022)

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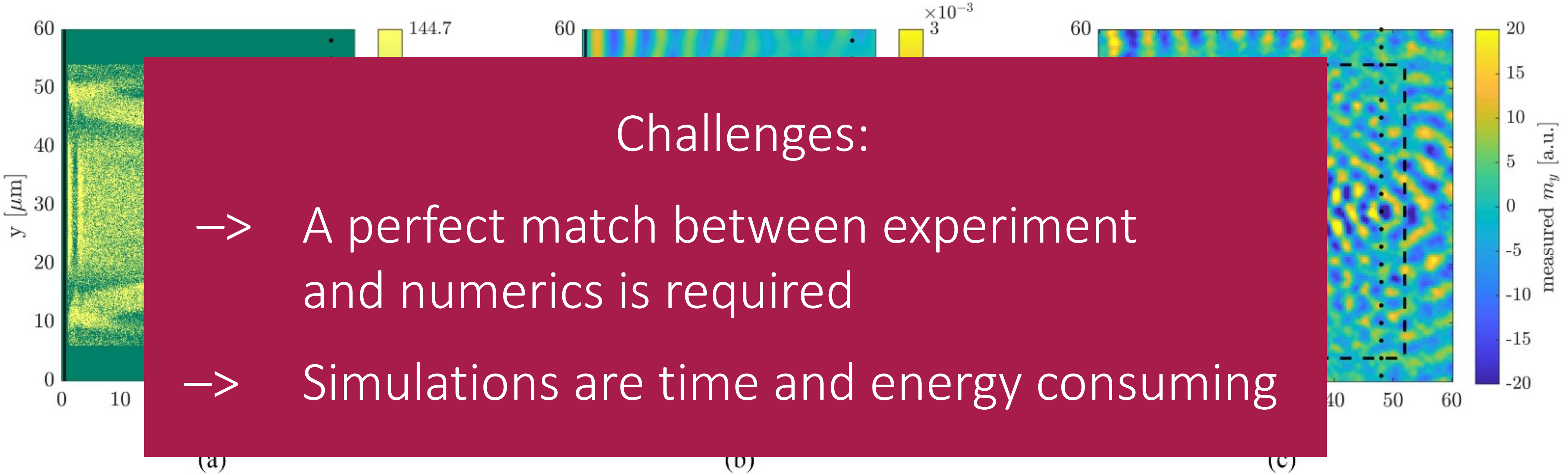
Experimental Demonstration of a Spin-Wave Lens Designed with Machine Learning



Challenges:

–> A perfect match between experiment and numerics is required

–> Simulations are time and energy consuming

Fig. 3. Focusing of spin waves by a machine-learning-designed magnetization pattern. (a) SpinTorch uses the two values $M_{\mathrm{eff},0}$ and $M_{\mathrm{eff,FIB}}$ as training parameters, and constructs a binary nontrivial saturation magnetization map by the inverse-design algorithm. (b) Plane wave propagation through the pattern in (a) simulated in mumax^3. (c) Measured spin wave waveform in the FIB-irradiated magnetization pattern, showing the wavefront focusing to the center output. The dashed rectangle corresponds to the 50 × 50 μm design area used for the training.

Kiechle, et al. IEEE Mag. Lett. 13, 6105305 (2022)

Experimental inverse-design unit

arXiv > physics > arXiv:2403.17724

Search...

Help | A

Physics > Applied Physics

[Submitted on 26 Mar 2024]

Magnonic inverse-design processor

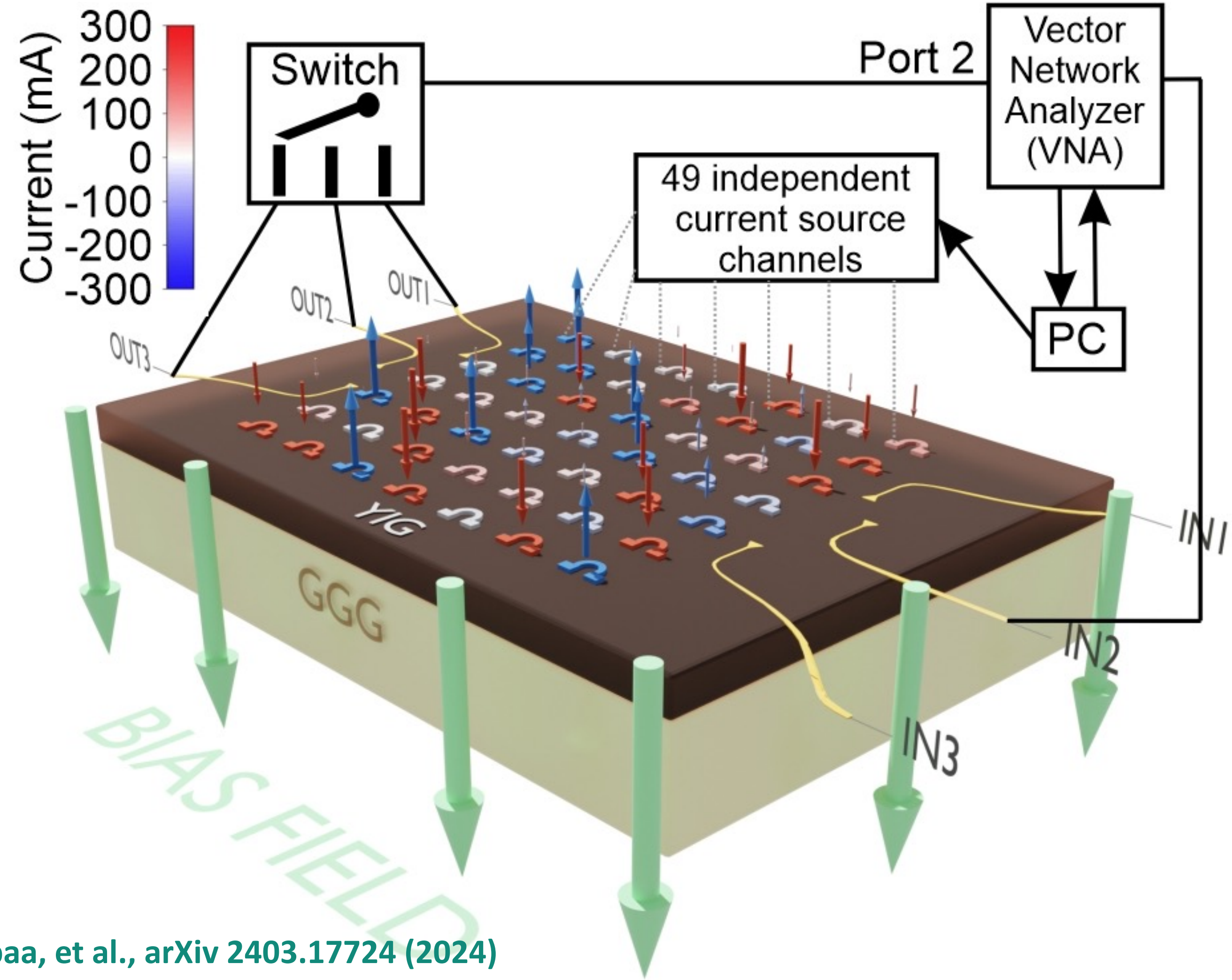
Noura Zenbaa, Claas Abert, Fabian Majcen, Michael Kerber, Rostyslav Serha, Sebastian Knauer, Qi Wang, Thomas Schrefl, Dieter Suess, Andrii Chumak

Artificial Intelligence (AI) technology has revolutionized our everyday lives and research. The concept of inverse design, which involves defining a functionality by a human and then using an algorithm to search for the device's design, opened new perspectives for information processing. A specialized AI-driven processor capable of solving an inverse problem in real-time offers a compelling alternative to the time and energy-intensive CMOS computations. Here, we report on a magnon-based processor that uses a complex reconfigurable medium to process data in the gigahertz range, catering to the demands of 5G and 6G telecommunication. Demonstrating its versatility, the processor solves inverse problems using two algorithms to realize RF notch filters and demultiplexers. The processor also exhibits potential for binary, reservoir, and neuromorphic computing paradigms.

Subjects: **Applied Physics (physics.app-ph)**; Materials Science (cond-mat.mtrl-sci)
Cite as: arXiv:2403.17724 **[physics.app-ph]**
(or arXiv:2403.17724v1 **[physics.app-ph]** for this version)
https://doi.org/10.48550/arXiv.2403.17724

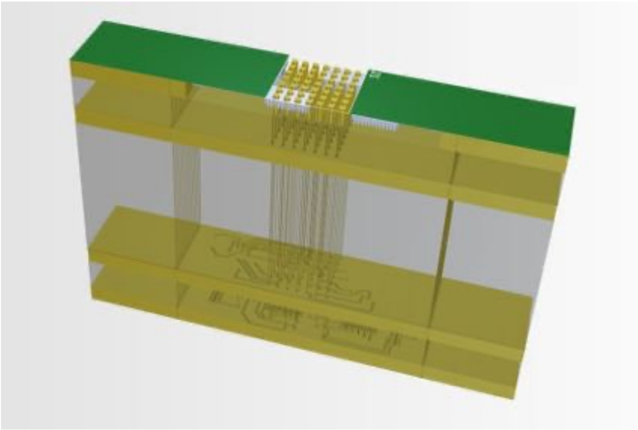
Zenbaa, et al., arXiv 2403.17724 (2024)

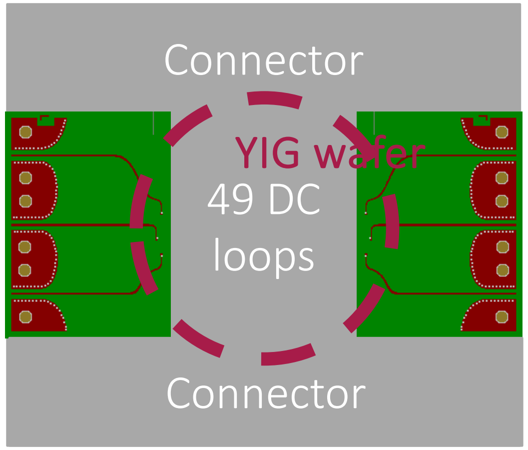
Experimental inverse-design unit



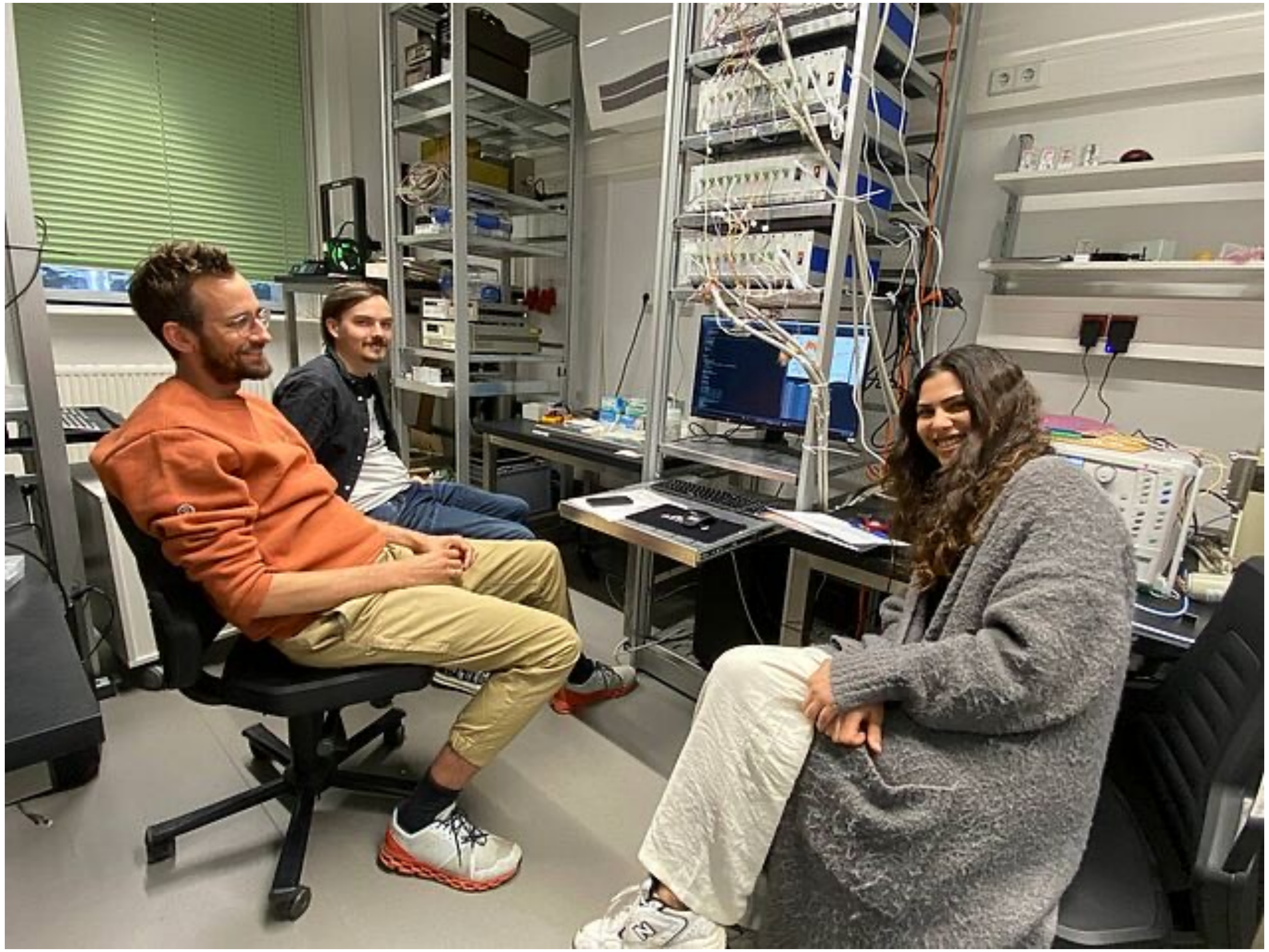
Zenbaa, et al., arXiv 2403.17724 (2024)

18 μm thick YIG
350 mT OOP biasing field





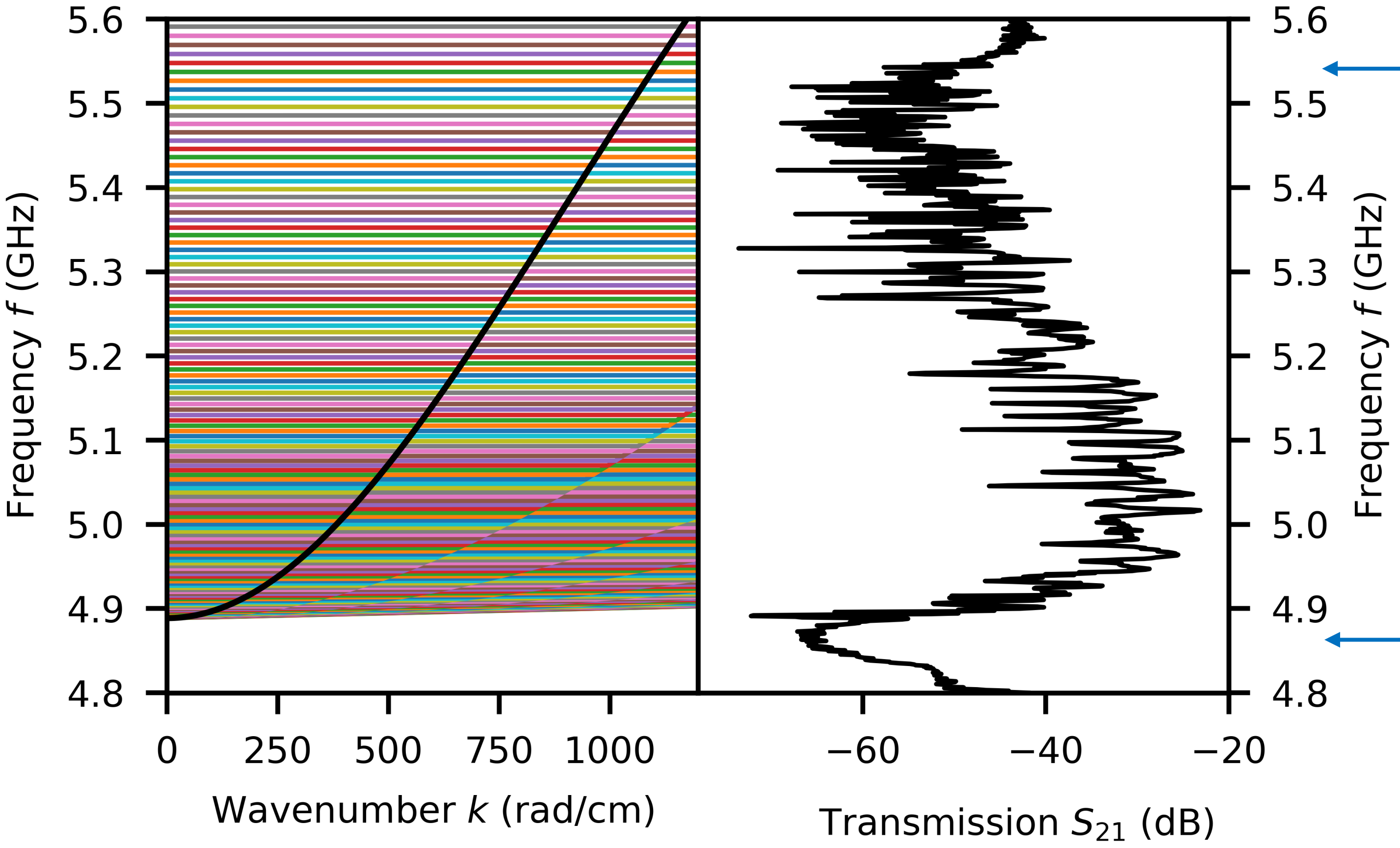
First run



Fabian Majcen,
Claas Abert,
Noura Zenbaa

Propagating spin wave spectrum

18 μm thick YIG
350 mT bias field

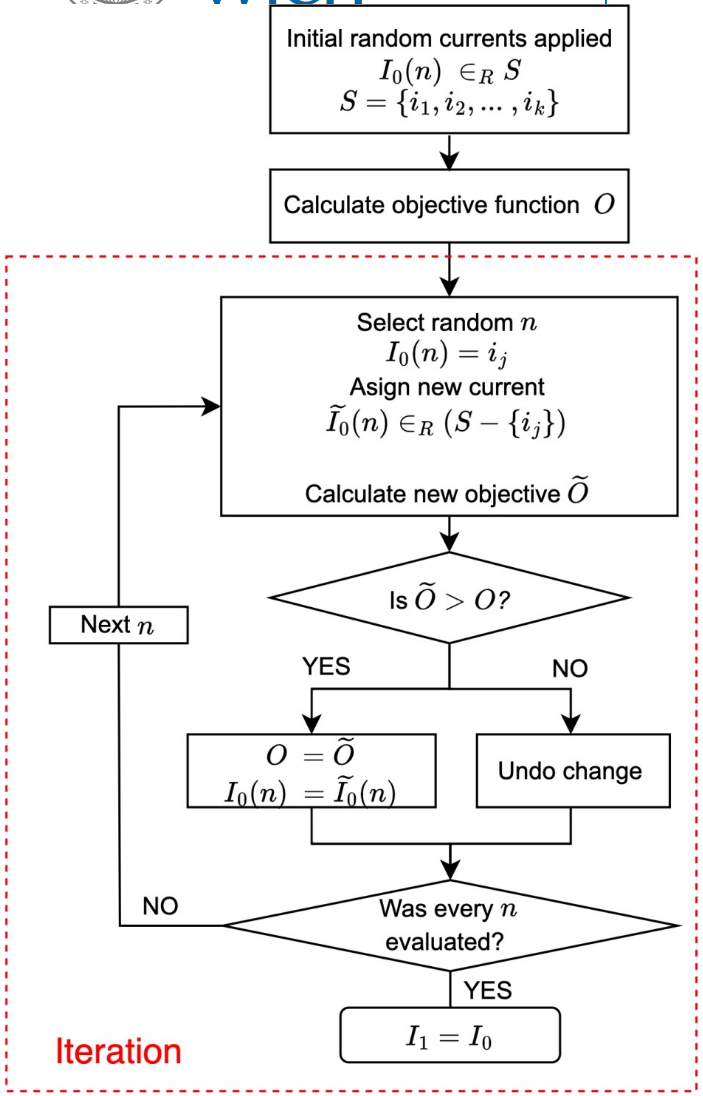


K_{max} = 0.111 rad/μm

K_{min} = 3.55 rad/cm

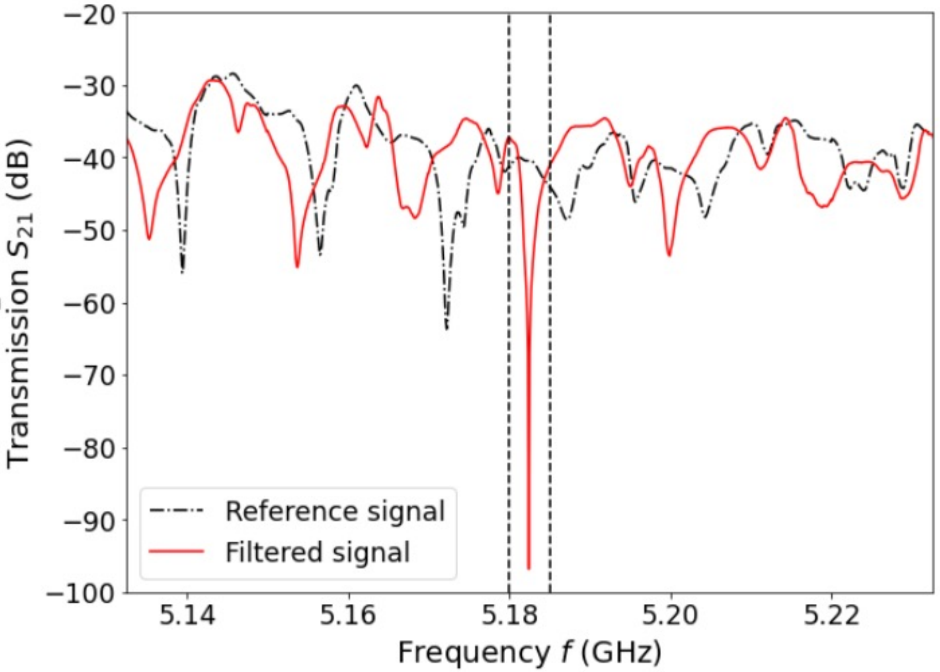
Zenbaa, et al., arXiv 2403.17724 (2024)

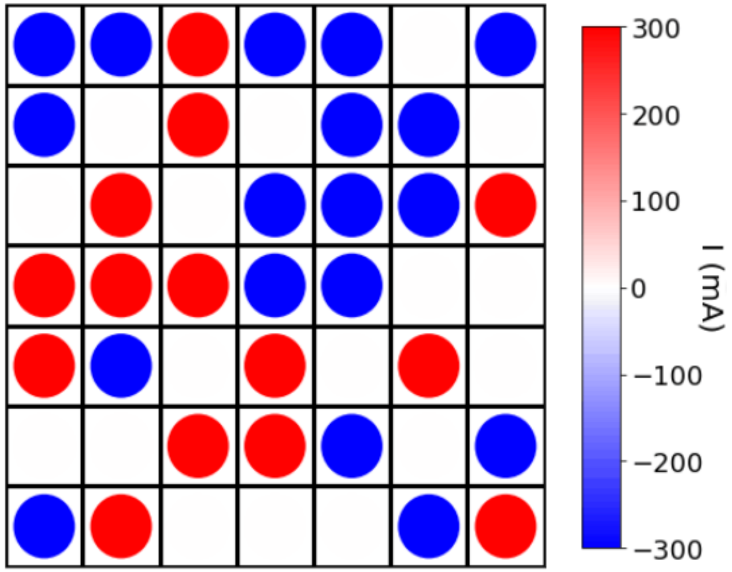
Direct Search optimization



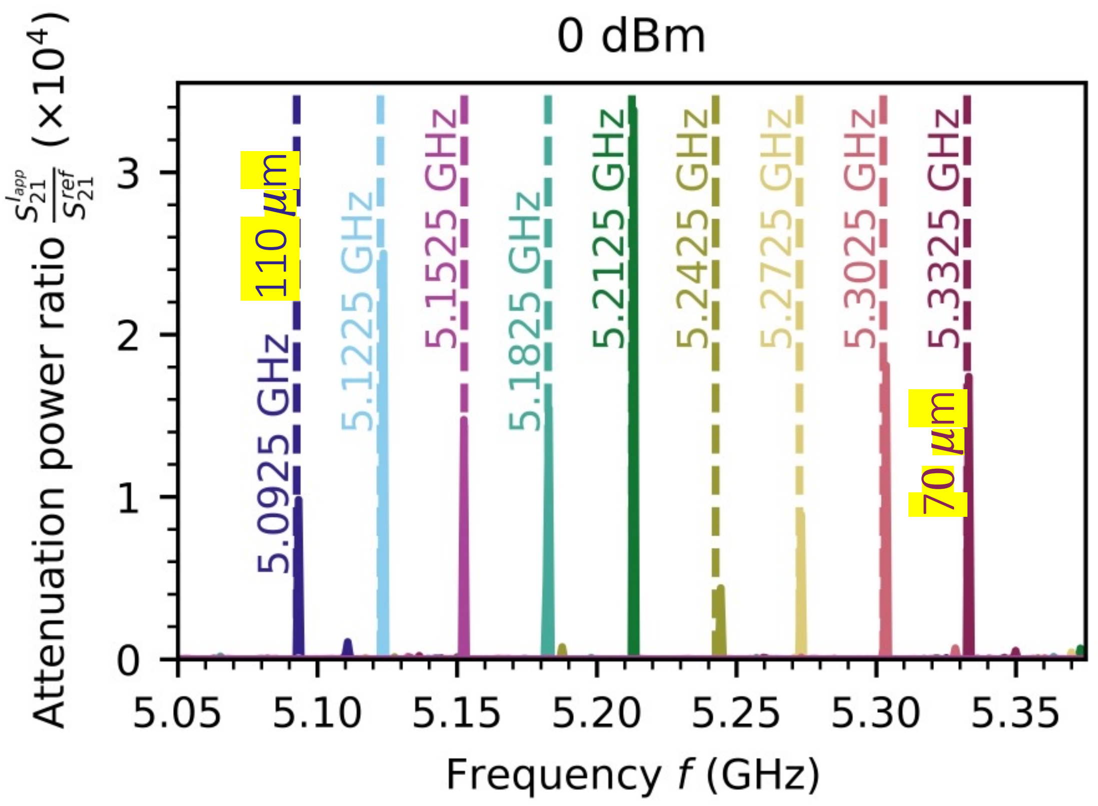
$$O_j^{\mathrm{DS}} = (S_{21}^{\mathrm{ref}} - S_{21,j}^{\mathrm{I_{app}}})_{\mathrm{filter\ BW}}$$

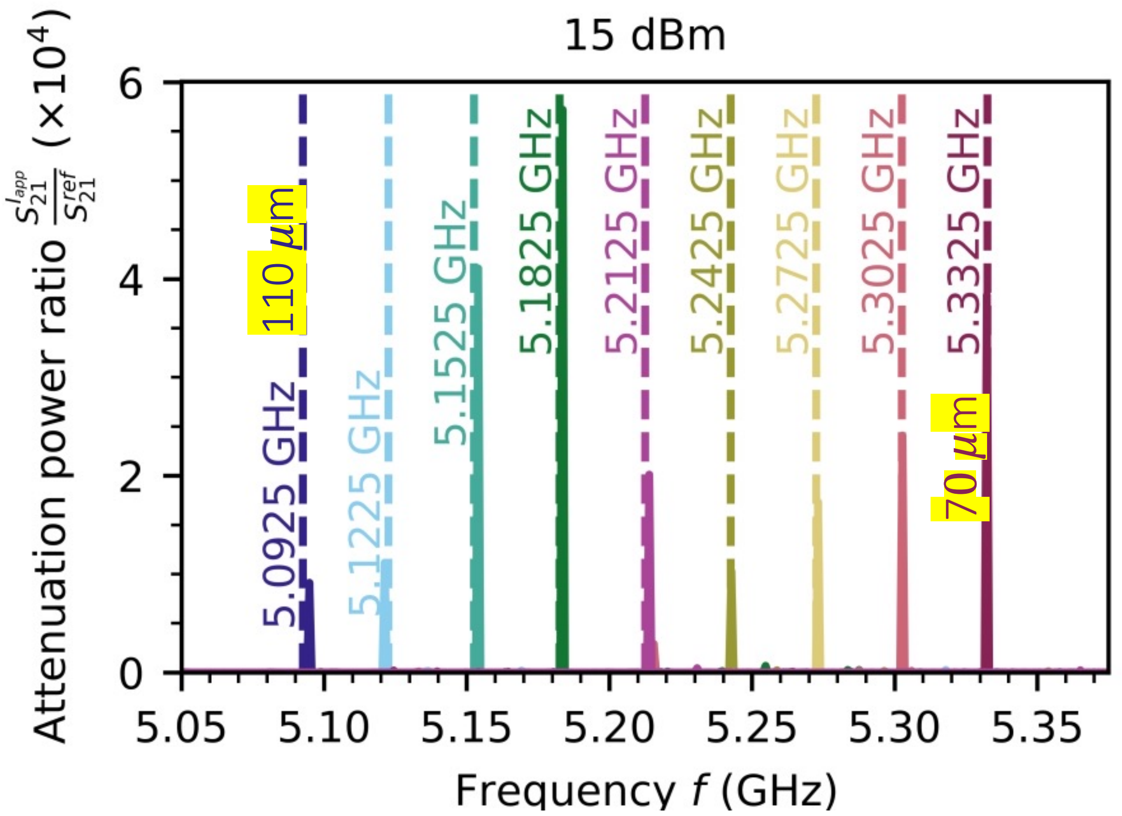
Configuration 393





Notch filter





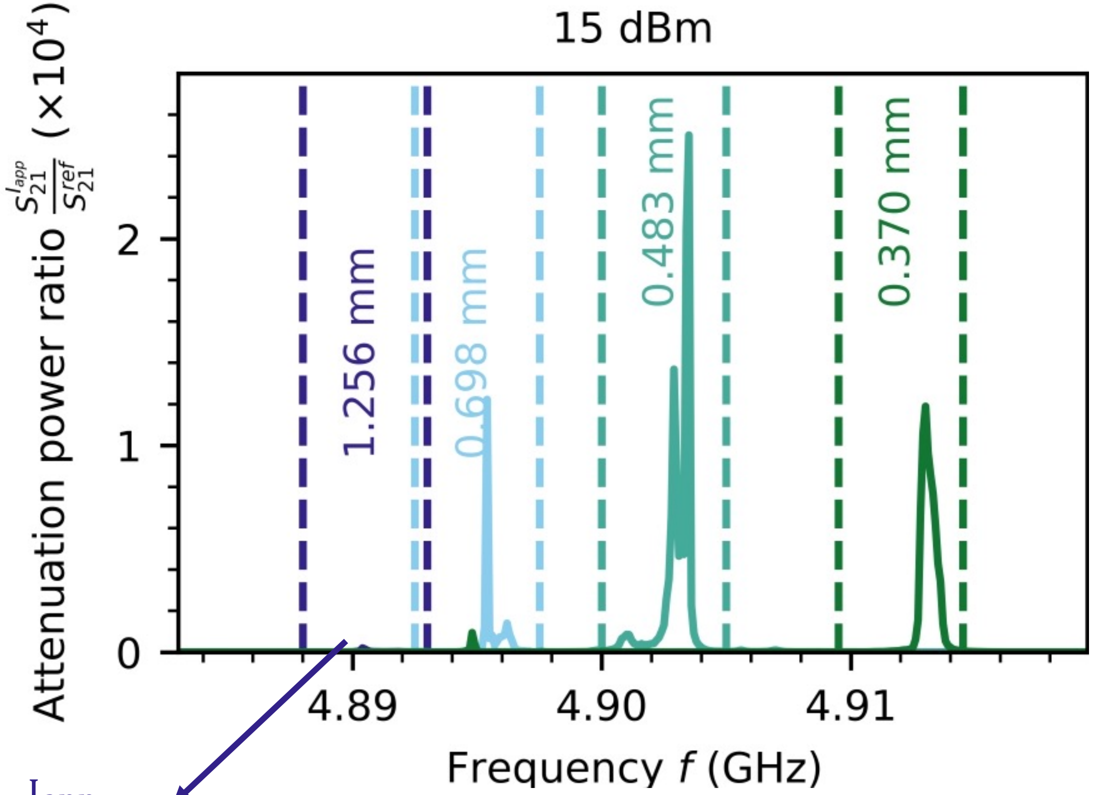
Notch filter bandwidth = 5 MHz
9 center frequencies
2 different powers

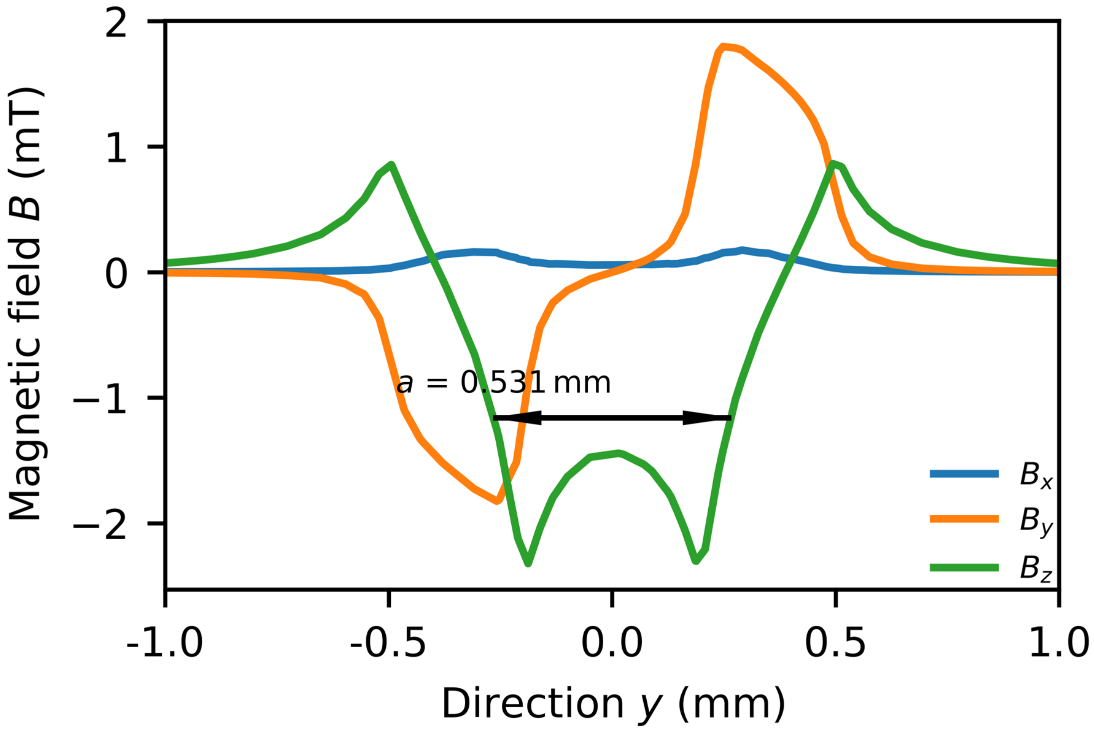
$$\text{Attenuation power ratio} = \frac{1}{10^{\frac{\Delta S_{21}(\text{dB})}{10}}}$$

$$\Delta S_{21}(\text{dB}) = S_{21}^{\text{I}_{\text{app}}} - S_{21}^{\text{ref}}$$

Zenbaa, et al., arXiv 2403.17724 (2024)

Notch filter





$$\frac{S_{21}^{\mathrm{I_{app}}}}{S_{21}^{\mathrm{ref}}} = 200$$

$$\text{Attenuation power ratio} = \frac{1}{10^{\frac{\Delta S_{21}(\mathrm{dB})}{10}}}$$

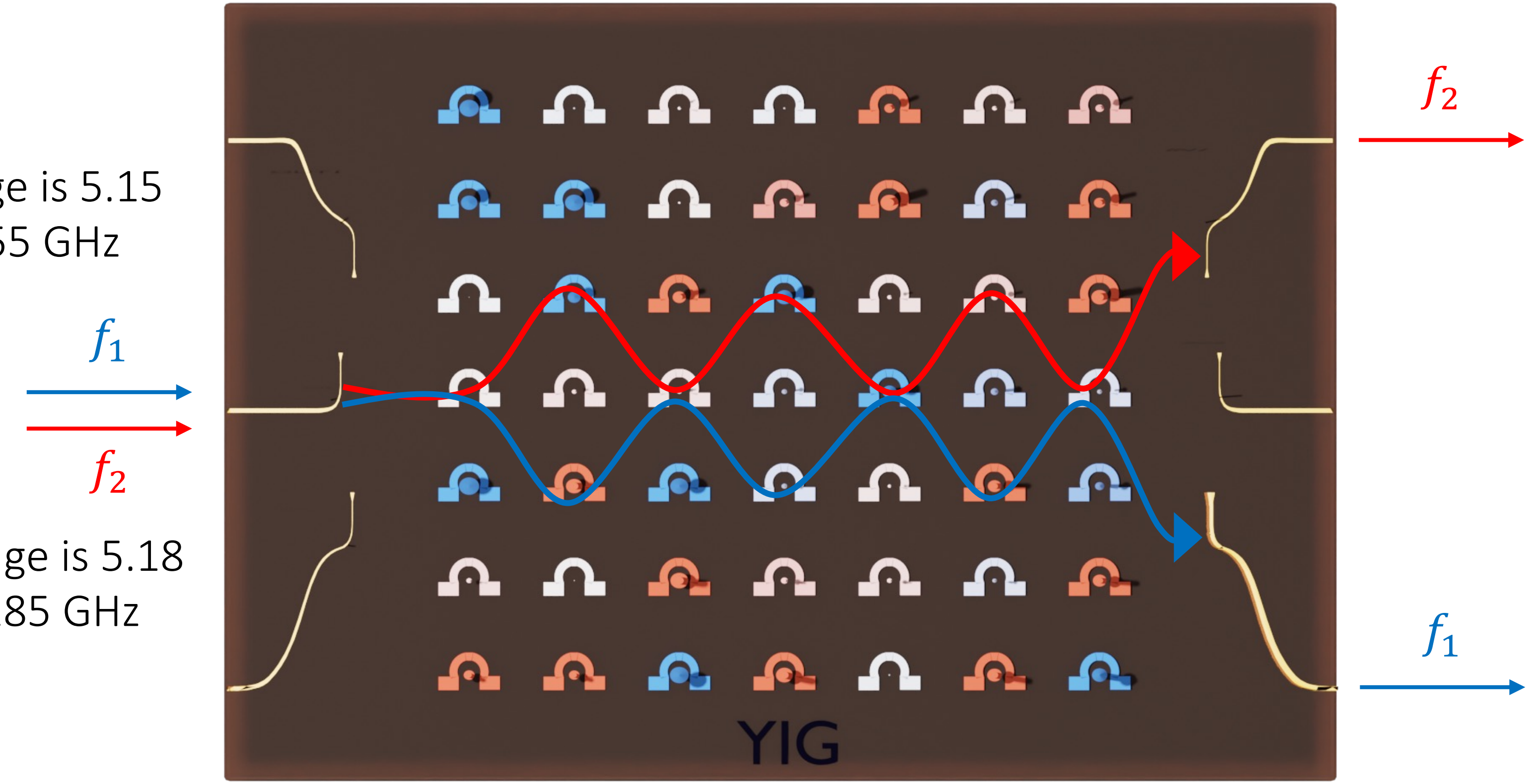
$$\Delta S_{21}(\mathrm{dB}) = S_{21}^{\mathrm{I_{app}}} - S_{21}^{\mathrm{ref}}$$

Two-port demultiplexer

$$O_j^{\mathrm{DS}} = (S_{21}^{\mathrm{ref}} - S_{21,j}^{\mathrm{I_{app}}})_{\mathrm{f_1,output_1}} \times (S_{21}^{\mathrm{ref}} - S_{21,j}^{\mathrm{I_{app}}})_{\mathrm{f_2,output_2}}$$

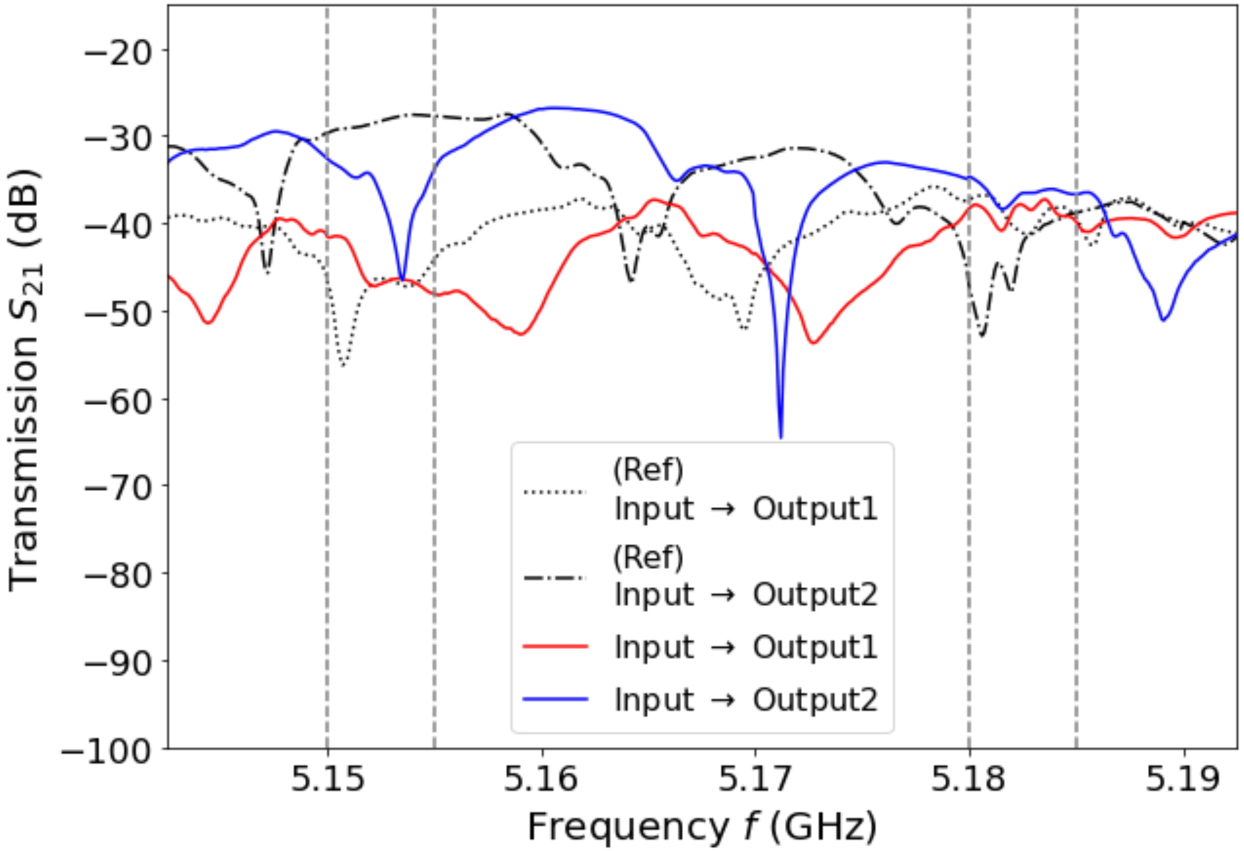
f_1 range is 5.15 to 5.155 GHz

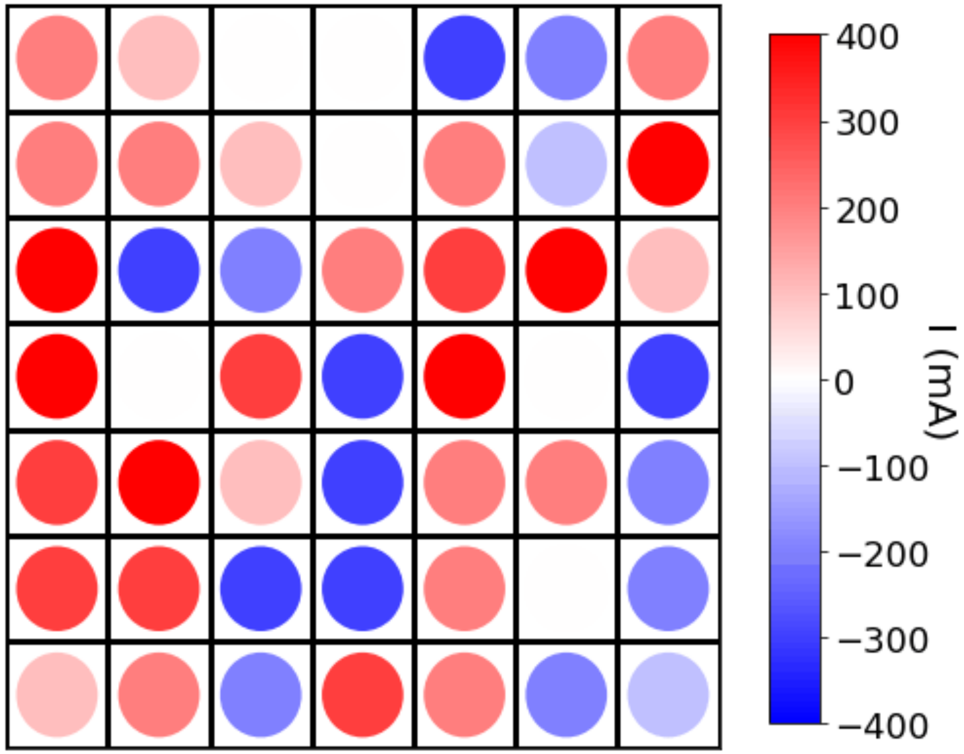
f_2 range is 5.18 to 5.185 GHz



Two-port demultiplexer

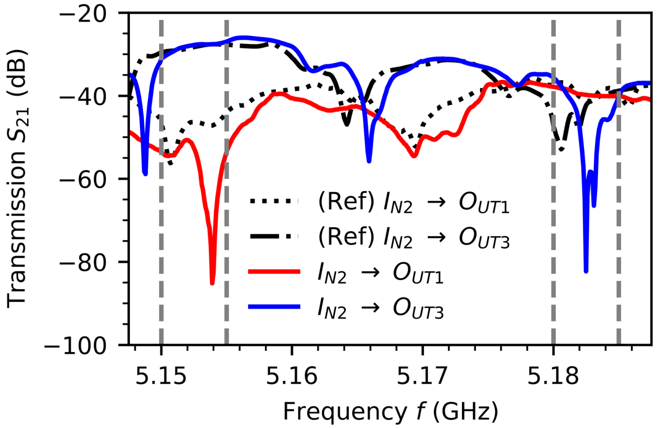
$$O_j^{\mathrm{DS}} = (S_{21}^{\mathrm{ref}} - S_{21,j}^{\mathrm{I_{app}}})_{\mathrm{f_1,output_1}} \times (S_{21}^{\mathrm{ref}} - S_{21,j}^{\mathrm{I_{app}}})_{\mathrm{f_2,output_2}}$$

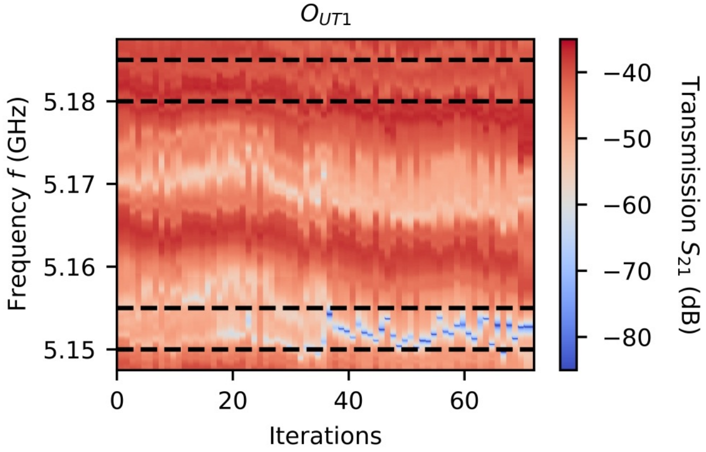


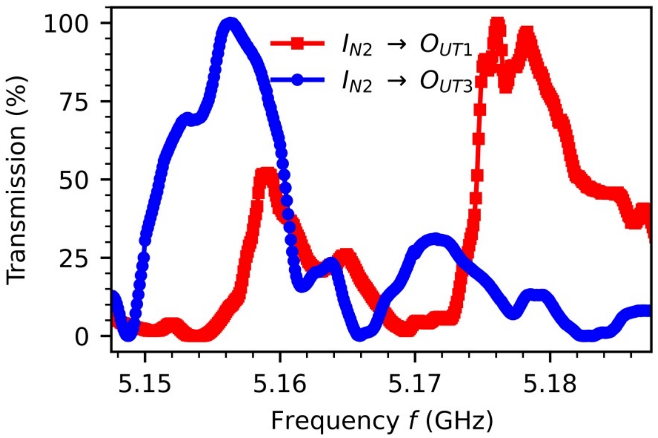


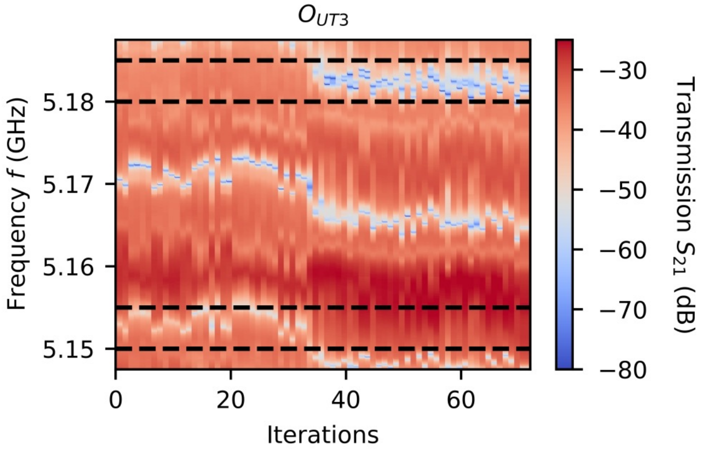
Two-port demultiplexer

$$O_j^{\mathrm{DS}} = (S_{21}^{\mathrm{ref}} - S_{21,j}^{\mathrm{I_{app}}})_{\mathrm{f_1,output_1}} \times (S_{21}^{\mathrm{ref}} - S_{21,j}^{\mathrm{I_{app}}})_{\mathrm{f_2,output_2}}$$









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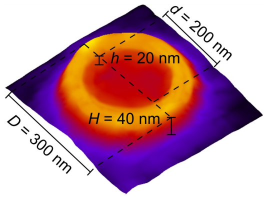
Tenured Senior Scientist position to be announced soon

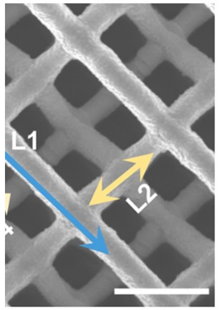
- Experimental magnonics
- Group of Nanomagnetism and Magnonics, Faculty of Physics, University of Vienna
- Tenured (after some period)

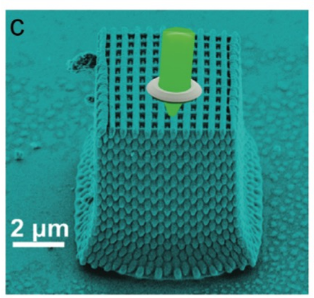
Please write to: *andrii.chumak@univie.ac.at*

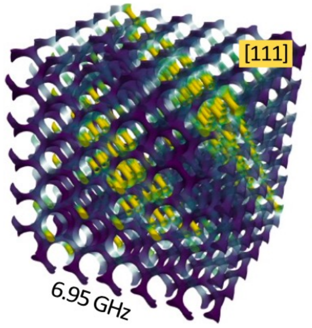
Conclusions

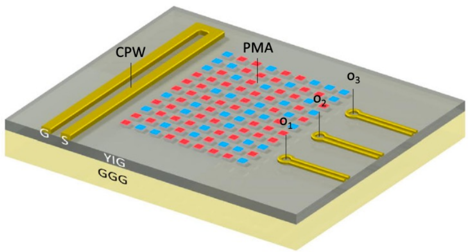
3D magnonics has great potential for guiding and processing information

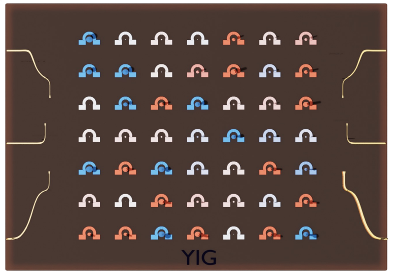


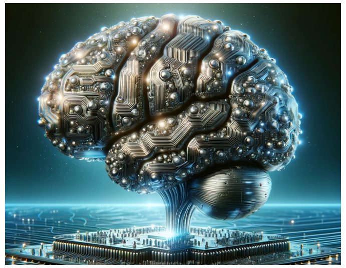












Merging 3D magnonics with inverse design opens new opportunities

Thank you for your attention!

Challenges:

- Quality and choice of nano-materials
- (Localised) SW excitation and (3D) detection
- Limited computational power/memory