



Magnetocaloric high-entropy alloys: prospects and challenges

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Thank you

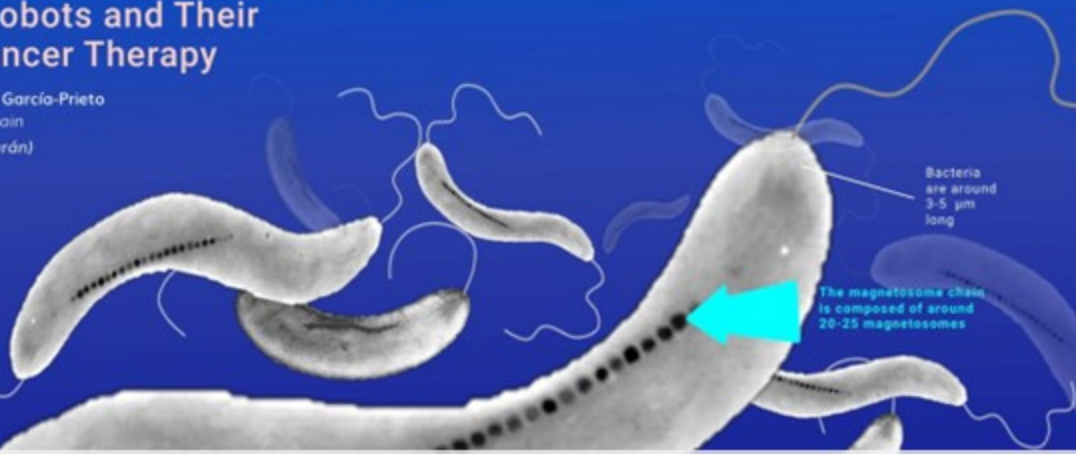
CemMAG

Club Español de Magnetismo

Magnetotactic Bacteria:

Biological Nanorobots and Their Suitability for Cancer Therapy

by M^a Luisa Fdez-Gubieda and Ana García-Prieto
University of the Basque Country, Spain
(graphics by José Manuel Barandiarán)



Magnetotactic bacteria are aquatic microorganisms that can orient and navigate in geomagnetic field lines due to the presence of a chain of magnetic nanoparticles known as magnetosomes. The magnetosome chain functions like a compass needle. They were discovered in 1963 by Salvatore Bellini and rediscovered and classified in 1975 by Richard Blakemore.

Bacteria are around 3-5 µm long

The magnetosome chain is composed of around 20-25 magnetosomes

Thank you CEMAG family for your support in my Editor role in

Newsletter
November 2022

Newsletter of the IEEE Magnetics Society
Volume 62 | Issue 4 | November 2022
Editor: Jia Yan Law

In this issue:

- 1 From the President By Rosalind Knapton
- 2 "Magnetism for Ukraine 2022" By Zsolt Kármán, András Tóth and Zoltán Pálinkás
- 3 Research for Progress: The 2022 IEEE International Magnetics Society Conference
- 4 ABOUT THE COVER: A Personal View on Organizing a Conference in Challenging Times
- 5 The Joint IEEE InterMag 2022 Experience
- 6 Including Students' Comments: Magnetics High School Project and Outreach
- 7 Laboratory Electromagnetics Day 2022
- 8 Third Joint Executive Meeting of the IEEE Magnetics Society Chapters in Japan and the Magnetics Society of Japan
- 9 IEEE Magnetics Society at the International Conference on Electrical Machines (ICEM 2022)
- 10 Caltech 2022 in Cambridge
- 11 Trends in Magnetism 2022: A Conference in the Virtual Age
- 12 The 2022 IEEE Annual Meeting of the IEEE Magnetics Society
- 13 The Incoming Committee Chairs' View on the 2022 IEEE Annual Meeting
- 14 Around the Globe: Magnetics Society Chapters in Japan and the Magnetics Society of Japan
- 15 Search for the Next Incoming IEEE Annual Meeting
- 16 Incoming Committee Chair
- 17 IEEE Student Membership Movement
- 18 New Senior Members
- 19 The IEEE Magnetics Society Standards Committee (MSSC)
- 20 IEEE Magnetics Society International Lecturers for 2023
- 21 Students in Magnetism (SME)
- 22 Teaching and Communicating Magnetism
- 23 From the Editor
- 24 Conference Calendar
- 25 About the Newsletter

IEEE MAGNETICS

Although it may be generally accepted, some members of our society are different from others. Some may be more outgoing, while others may be more reserved. Our members are diverse in many ways, and it is this diversity that makes our society so rich and interesting.

If you say that you could save time by not reading this article, then this article is for you.

Less Is Not More

Comments can be tricky. It is easy for me to say "less is not more," but it is hard to do so in a way that is not misleading.

The expression "less is not more" often means that the original value is 5, "10 times more" is 5 * 10 = 50, and it is usually 10 * 5 = 50, for which we would prefer the expression "10 times as much" or "10 times more".

The expressions "10 times smaller" and "10 times larger" are logically suspect and do not mean what we often think they mean. For example, if the original value is 5, "10 times smaller" would be 5 / 10 = 0.5, and "10 times larger" would be 5 * 10 = 50. What we mean by "10 times smaller" is "10 times less" or "one order of magnitude smaller".

Instead of writing that something is 10 times smaller, it is better to write "10 times less" or "one order of magnitude smaller".

"Because," "as," and "since" are often used interchangeably, but they are not. "Because" creates ambiguity. Here are some examples:

"The color of the strip changed to pink because the intended meaning that the color became acidic, or is it that the color of the strip changed to pink since the intended meaning that the color became acidic, or is it that the color of the strip changed to pink as the intended meaning that the color became acidic?"

I would advise one to use "because" in preference to "since" or "as".

Current Trends in Magnetism, Joint IEEE InterMag 2022, New Orleans, USA

which was an effective way to promote discussion.

Another factor that was very critical for us was the safety and peace of mind of the attendees and their families. Many of us haven't experienced that type of situation since the COVID outbreak, yet we asked people to travel to the US alone abroad. Travel was difficult, and rules were changing nonstop. Therefore, in December 2021, Jagan and I set off for a conference in Charlotte to rehearse how it was to travel internationally in those circumstances. We were among the very few overseas attendees. That conference confirmed my previous hunch that we needed a COVID testing site at the conference hotel if we did not want international travelers to be put through significant stress. So, we made arrangements to make that happen in New Orleans.

As mentioned above, the only certainty that we had when planning the conference was that it was full of uncertainties. The expected around 400 attendees on-site, and that was the number of on-site registrations that we had a few weeks before the conference. Unfortunately, the Division variant outbreak coincided with the moment when people had to finalize their travel plans. As a result, we lost a significant fraction of ~40% of the on-site audience just one week before the event. We allowed people to change their registration to online and adapted the on-site program. The Program Co-Chair did a terrific job of keeping the sessions full and avoiding empty gaps in the schedule. Live modern production systems, we had to adapt a "just-in-time supply chain" philosophy to all this reshuffling.

Members of the Club Friends of Magnetism at the Joint IEEE InterMag 2022

ber
ee

I am a professor at the University of Oviedo in Spain. I lead a multidisciplinary team made up of physicists, chemists, engineers, and biotechnologists who are dedicated to exploring and developing and applying nanoparticles and magnetic sensors in the life sciences. In addition, I am the Editor-in-Chief of the Magnetics Society section of the IEEE Access Journal and an Associate Editor of IEEE Magnetics Letters.

Ever since I first attended an InterMag networking event, I have been hooked. It broadened my perspective in many ways, for example, by giving me the confidence to request professional advice from a colleague or to be nominated for an invited talk. I was a young researcher at that time and had the chance to learn that advised senior researchers were approachable people who were honored about themselves.

I gained self-confidence from it, which helped me expand my network of contacts.

That is why I am so motivated and happy to serve as the WM subcommittee chair, and I hope to live up to the standards of the women who have preceded me in this role.

I hope to see you in Sendai at InterMag 2023 to enjoy a worthwhile conference and an exciting WM networking event.

As of January 1, 2023, I was appointed to be the chair of this subcommittee, and I am confident that I will meet your expectations. I welcome your ideas and suggestions.

a while, "Women in Magnetism" initiatives pioneered by a group of female volunteers in the Magnetics Society. They did hard to offer our female members, especially our senior members, educational bodies (such as the leadership conferences, social events, the "women networking" at our flagging events), and the "Women platform" (WM) list.

In November 2022, the IEEE Magnetics Society Administrative Committee established the WM Subcommittee under the Membership Committee to improve the development and integration of WM in the Society.

Click to join the mailing list to receive news about events and job opportunities and to participate in discussions about female researchers in magnetism.

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The Write Stuff: WRITE LITERALLY

by Ron Goldfarb, President Elect, IEEE Magnetics Society

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IEEE MAGNETIC SOCIETY NEWSLETTER | V. 62, 4 | ISSUE 4 | SEP 2022

IEEE MAGNETIC SOCIETY NEWS

Magnetotactic Bacteria:

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Newsletter
November

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Volume 62 | Issue 4 | November 2022

Editor: Jia Yan Law

IEEE
MAGNETICS
SOCIETY

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- 1 From the President By Houshuo Han
- 2 "Magnetics for Ukraine 2022" By Sara Haddad, Anne Schmitt, and the team
- 3 Request for Proposals for the 2023 IEEE International Magnetics Society Conference
- 4 ABOUT THE COVER: A Personal View on Organizing a Conference in Challenging Times
- 5 The Joint MMN-Intermag 2022 Experience
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- 12 The 2022 IEEE Around the Clock Around the Globe Magnetics Conference
- 13 The Steering Committee Chairs' View on the 2022 IEEE Around the Clock Around the Globe Magnetics Conference
- 14 Search for the Next Incoming IEEE Around the Clock Around the Globe
- 15 Incoming Committee Chair
- 16 IEEE Student Membership Statement
- 17 New Senior Members
- 18 The IEEE Magnetics Society Standards Committee (SMSC)
- 19 IEEE Magnetics Society International Lecturers for 2023
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- 22 From the Editor
- 23 Conference Calendar
- 24 About the Newsletter



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Victorino Franco
Universidad de Sevilla, Spain
for contributions to the study of
thermomagnetic phase transitions, soft
magnets, and magnetocaloric materials
website

(1) What is your field of research/expertise?
I work on magnetic materials for energy applications, mainly soft magnetic materials and magnetocalorics. In addition, I have a strong interest in the development of new and/or optimized measurement techniques.

(2) What does it mean to you to be an IEEE Fellow?
When I started at University of Sevilla, it was not a place that was recognized for magnetism research. Over the years, this situation has changed and becoming a Fellow from within the Magnetics Society is the recognition that we do impactful research in this area. This is a significant achievement in my career and a great honor for which I am extremely thankful.

(3) What are your goals for 2024 and perhaps the next 5 years?
Being a physicist by training, my research is at the borderline between physics and materials science. My current goal is to bring my research closer to the society, implementing prototypes that attract industry to get onboard and improve our quality of life. Completing this goal will probably take me longer than that time.

(4) Is there any advice for young scientists and engineers that you would like to share?
My advice is twofold: dare to go out of your comfort zone and persevere in whatever you try.

(5) Would you be open to sharing a fun fact about yourself?
I still like to work in the lab, especially when it involves developing new measurement devices, programming data acquisition systems out of the ordinary, or even 3D printing parts for functional prototypes. And I like to combine these hobbies with visits to international labs, where I enjoy interacting with the local students in solving their experimental or simulation problems.

26 IEEE MAGNETICS SOCIETY NEWSLETTER | VOL. 64 | ISSUE 1 | MAR 2024

IEEE MAGNETICS SOCIETY NEWSLETTER | VOL. 64 | ISSUE 1 | MAR 2024 27



Joliet MMN-Intermag 2022, New Orleans, USA



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28 IEEE MAGNETICS SOCIETY NEWSLETTER | VOL. 63 | ISSUE 2 | SEP 2023

I am a professor at the University of Oviedo in Spain. I lead a multidisciplinary team made up of physicists, chemists, engineers, and biotechnologists who are dedicated to designing and developing, and using nanoparticles and electronic sensors in the life sciences. In addition, I am the vice-Chief of the Physics Society section of IEEE Access journal and an Associate Editor of IEEE Electronics Letters.

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That is why I am so motivated and happy to serve as the IEEE subcommittee chair, and I hope to live up to the standards of the women who have preceded me in this role. I hope to see you in Sendai at InterMag 2023 to enjoy a worthwhile conference and an exciting IEEE networking event.

Editor role in

Although it may be grammatically correct, using "more" or "less" is almost never the best choice. Other times, our words may be ambiguous, which can lead to misunderstandings. Our readers are aware of our intentions.

If you say that you could care less because literally, what you mean, then this article is for you.

Less Is Not More

Comparisons can be tricky. It is easy for us to half as long, but hard to be half as small or to be half as big.

The expressions "less" and "more" often mean the original value is 5, "10 times more" is 5 + (10 x 5) = 55, for which we would prefer "10 times as much" or "10 times as large".

The expressions "n times smaller" and "n times larger" are logically suspect and do not mean what we often intend. For example, if the "smaller" would be 5 + (10 x 5) = 55, what we mean is "10 times less" or "one order of magnitude smaller".

Instead of writing that something is 10 times as large, it is 10 times as small (but not 10 times smaller), or 10 times as long (but not 10 times longer), or 10 times as high (but not 10 times higher).

"Because," "as," and "since" are often used interchangeably, but "since" can create ambiguity. Here are examples:

"The color of the strip changed to pink since the intended meaning that the color became acidic, or is it that the color of the strip became acidic?"

"The color of the strip changed to pink because the intended meaning that the color became acidic, or is it that the color changed after the intended meaning that the color became acidic?"

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By Ron Goldfarb
President Elect
IEEE Magnetics Society

IEEE MAGNETICS SOCIETY NEWSLETTER

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Muñoz**



**Mr. Zhe
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Magnetocaloric high-entropy alloys: prospects and challenges

Jia Yan Law

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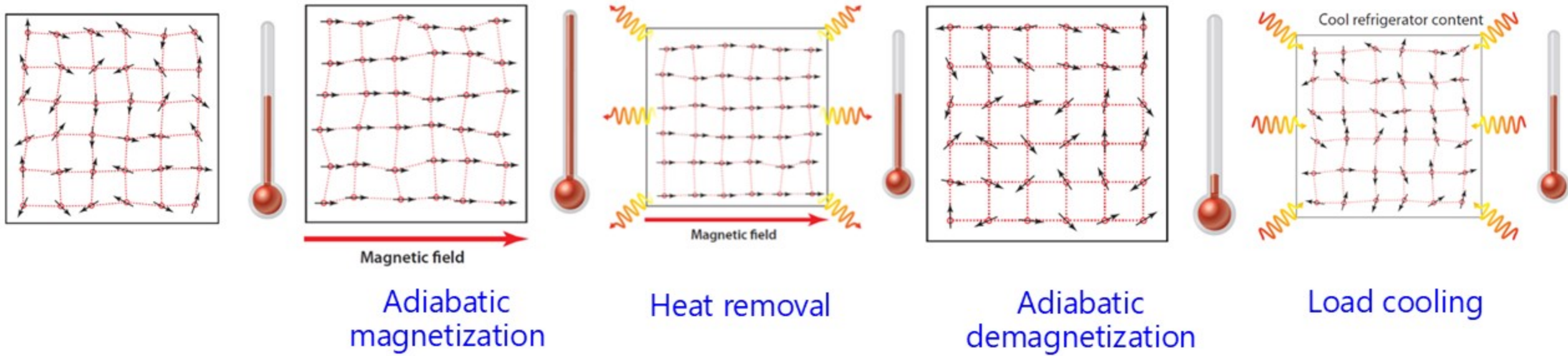
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magnetocaloric effect

refers to **adiabatic ΔT** of magnetic material
when subjected to **varying** magnetic field

4 stages of

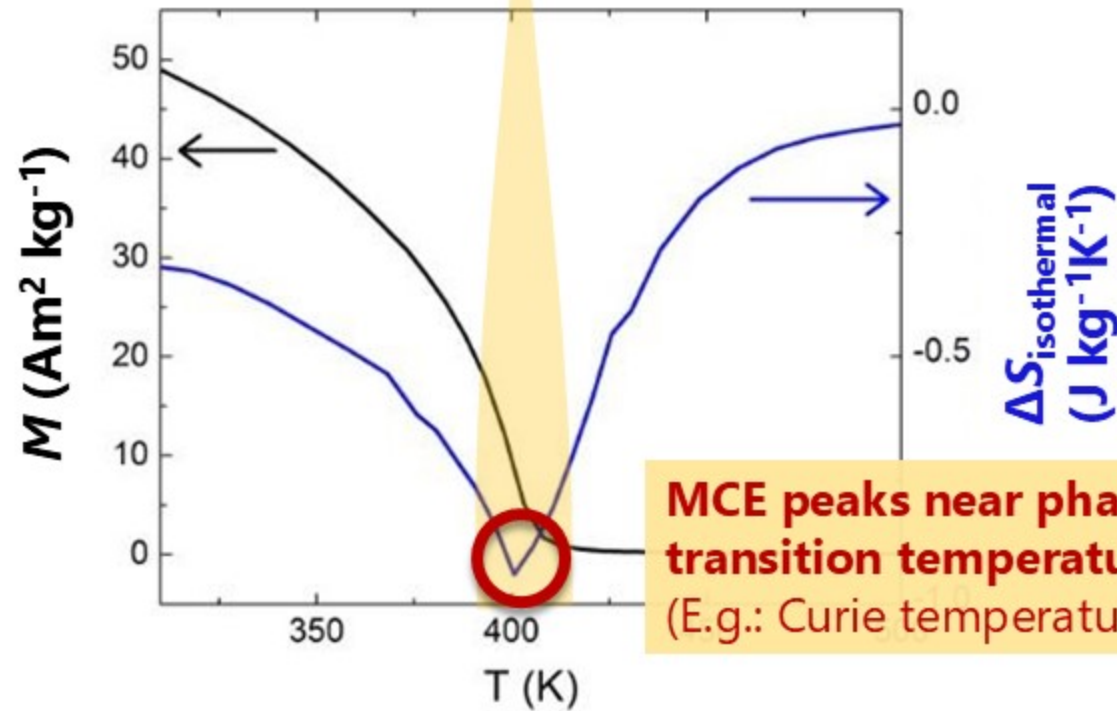
Magnetic Refrigeration Cycle



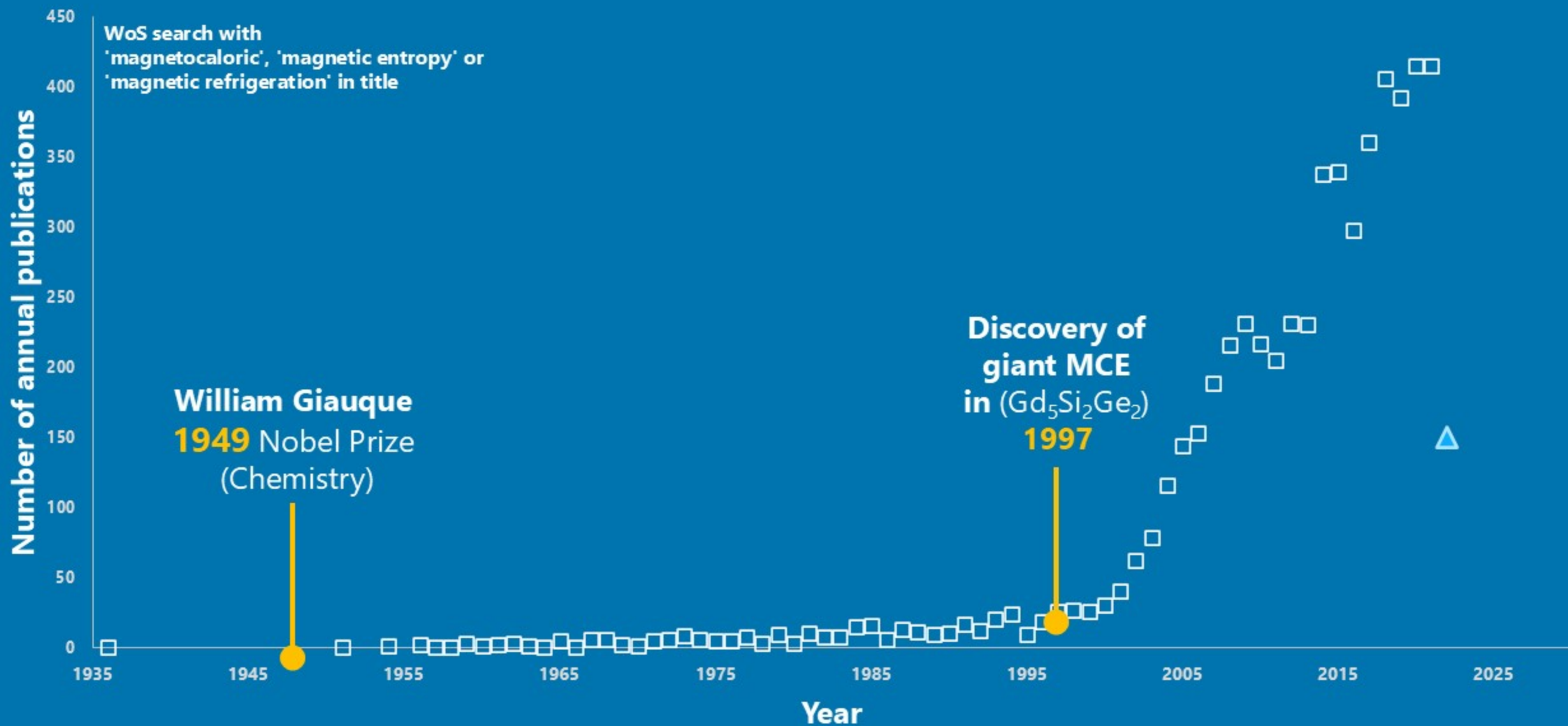
Magnetocaloric effect $\equiv \Delta T$ or $\Delta S_{\text{isothermal}}$

$\Delta S_{\text{isothermal}}$ commonly reported using the magnetic measurement data...

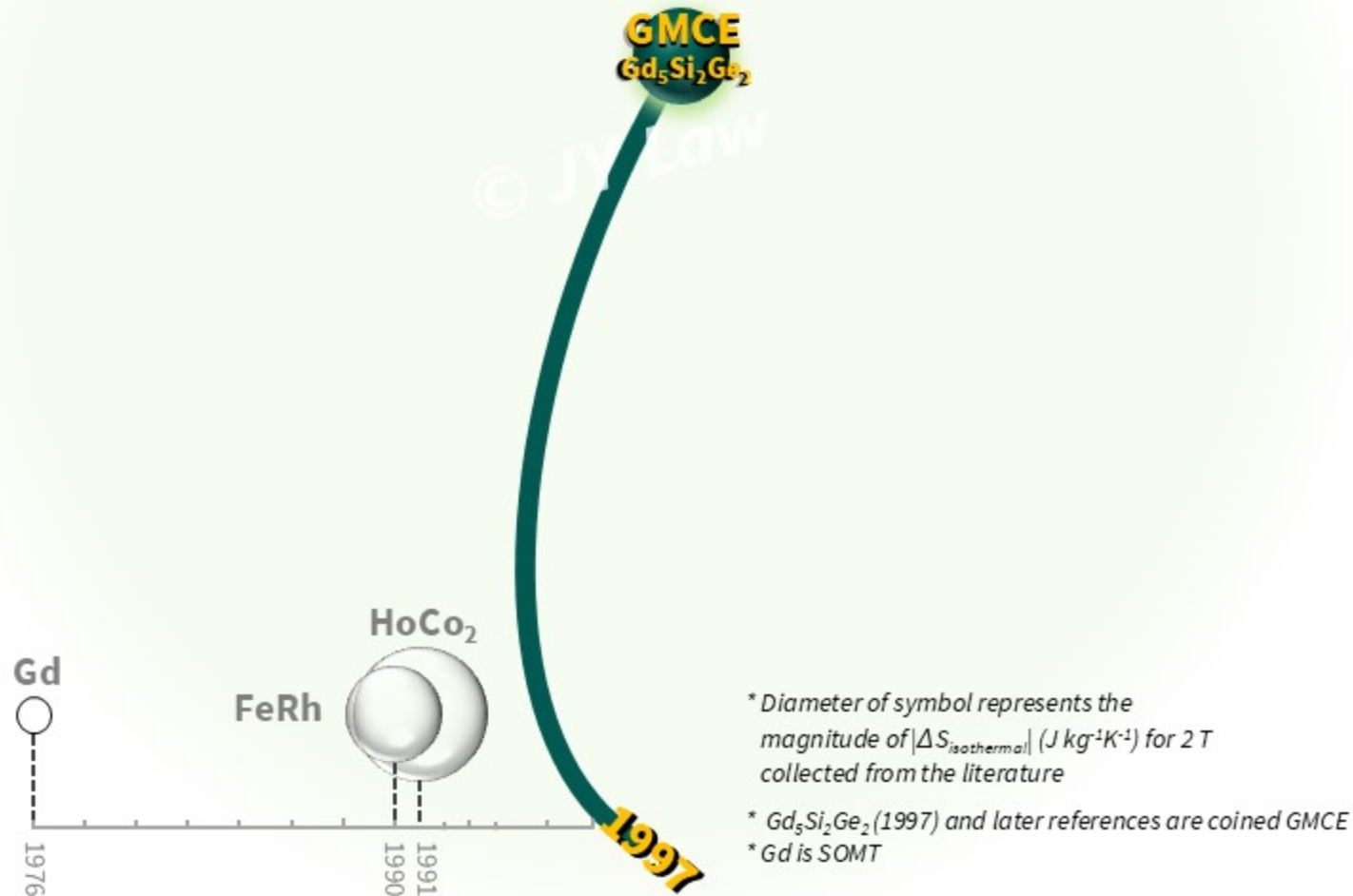
$$|\Delta S_{\text{isothermal}}| = \mu_0 \int_0^{H_f} \left(\frac{\partial M}{\partial T} \right)_H dH$$



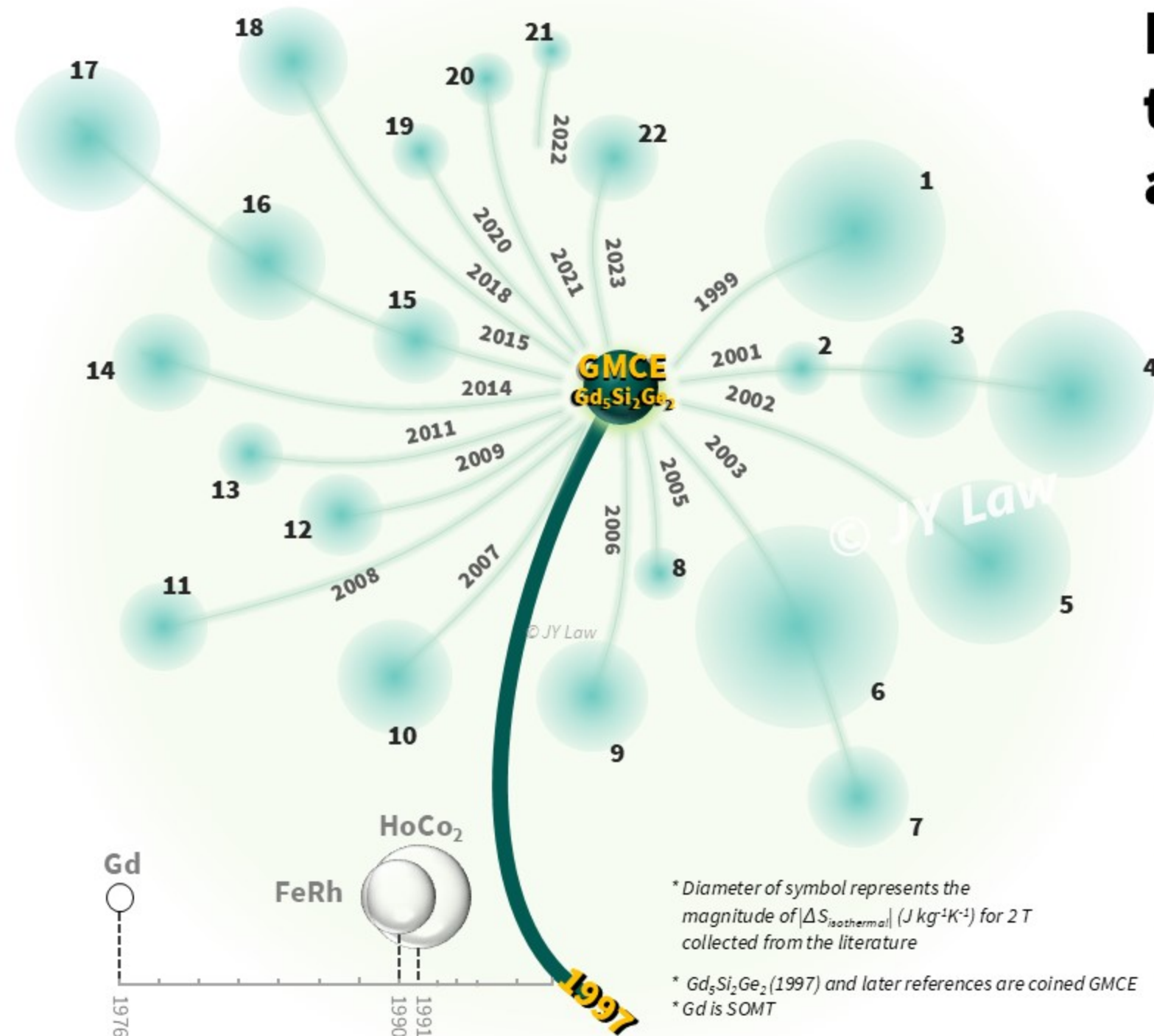
milestones



FOMT compounds that *flourished* after GMCE $\text{Gd}_5\text{Si}_2\text{Ge}_2$



FOMT compounds that *flourished* after GMCE $\text{Gd}_5\text{Si}_2\text{Ge}_2$



In Memoriam of
Vitalij K. Pecharsky
a brilliant scientist, caring mentor, and passionate leader devoted to understanding energy-relevant materials

By: Yaroslav Mulyuk and Laura Milligan
Ames Laboratory, USA

Vitalij K. Pecharsky, Ames National Laboratory Scientist and Ames-Markus Distinguished Professor in Iowa State University's Department of Materials Science and Engineering, died on Tuesday, December 20, 2023, aged 64. A brilliant scientist, caring mentor, and passionate leader, he devoted his life to the discovery and fundamental understanding of energy-relevant materials. He was interested in and made a lasting contribution to a variety of topics: basic and applications of x-ray powder diffraction, composition-structure-property relations in rare earth intermetallic compounds, experimental study, theory, and modeling of thermomagnetic phenomena, novel hard magnetic materials containing late-transition elements, and hydrogen storage materials. Above all, however, he will be remembered as one of the founding fathers of room temperature magnetocaloric refrigeration.

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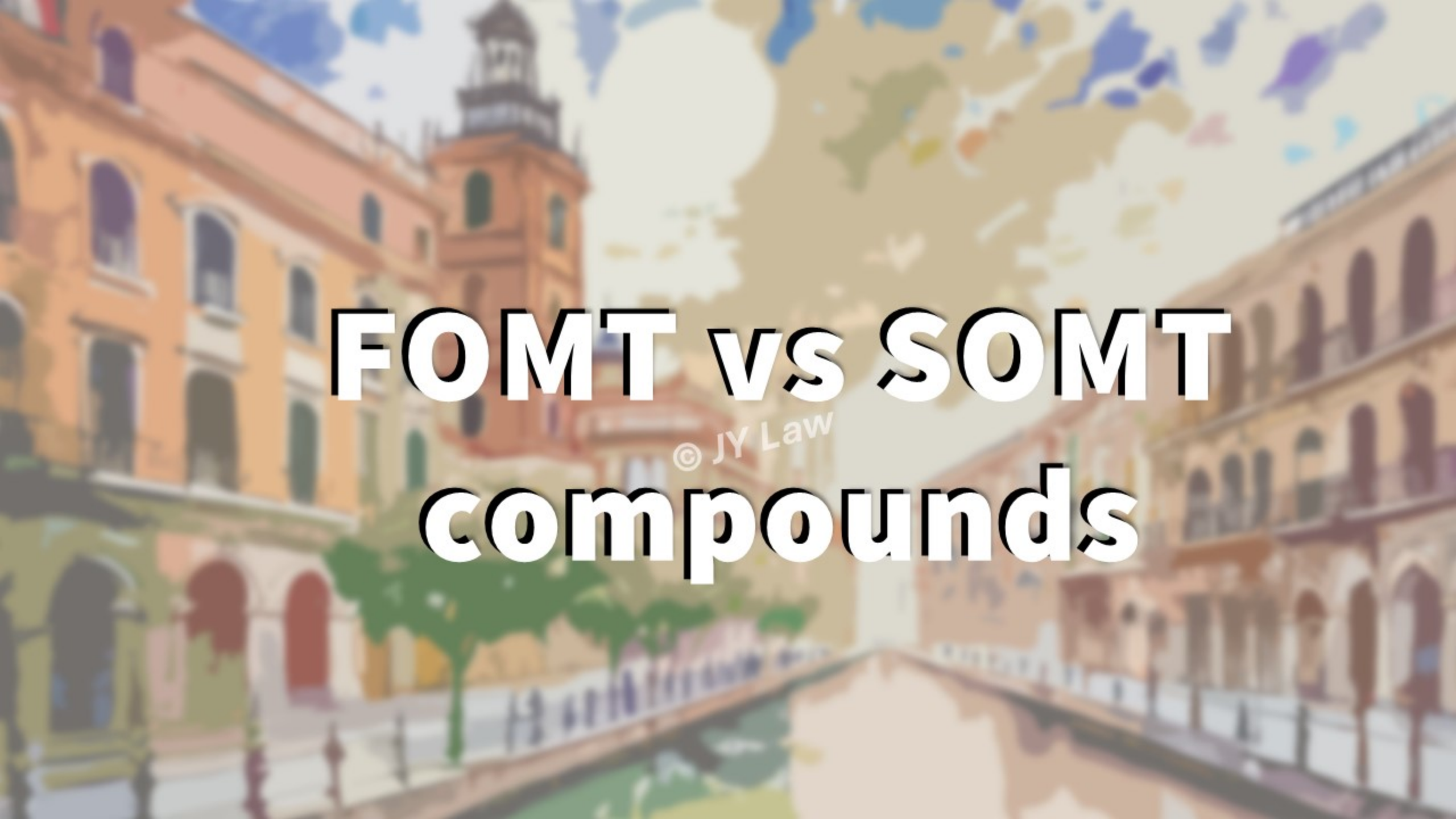
FOMT compounds that flourished after GMCE $\text{Gd}_5\text{Si}_2\text{Ge}_2$

1. $\text{Gd}_5\text{Si}_2\text{Ge}_2$
2. $\text{Gd}_5\text{Si}_2\text{Ge}_2$
3. $\text{Gd}_5\text{Si}_2\text{Ge}_2$
4. $\text{Gd}_5\text{Si}_2\text{Ge}_2$
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20. $\text{Gd}_5\text{Si}_2\text{Ge}_2$
21. $\text{Gd}_5\text{Si}_2\text{Ge}_2$
22. $\text{Gd}_5\text{Si}_2\text{Ge}_2$

* Diameter of sphere represents the magnitude of $|\Delta S_{\text{isothermal}}|$ ($\text{J kg}^{-1}\text{K}^{-1}$) for 2 T collected from the literature

* $\text{Gd}_5\text{Si}_2\text{Ge}_2$ (1997) and later references are coined GMCE

* Gd is SOMET



FOMT vs SOMT compounds

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1

Large ΔS_{iso}
No thermal hysteresis

MCE
• Larger ΔS_{iso}
• Narrow T_{span}
• Hysteresis
• Rate-dependent behavior

1st order

2

Moderate ΔS_{iso}
• wider T_{span}
• No thermal hysteresis

2nd order

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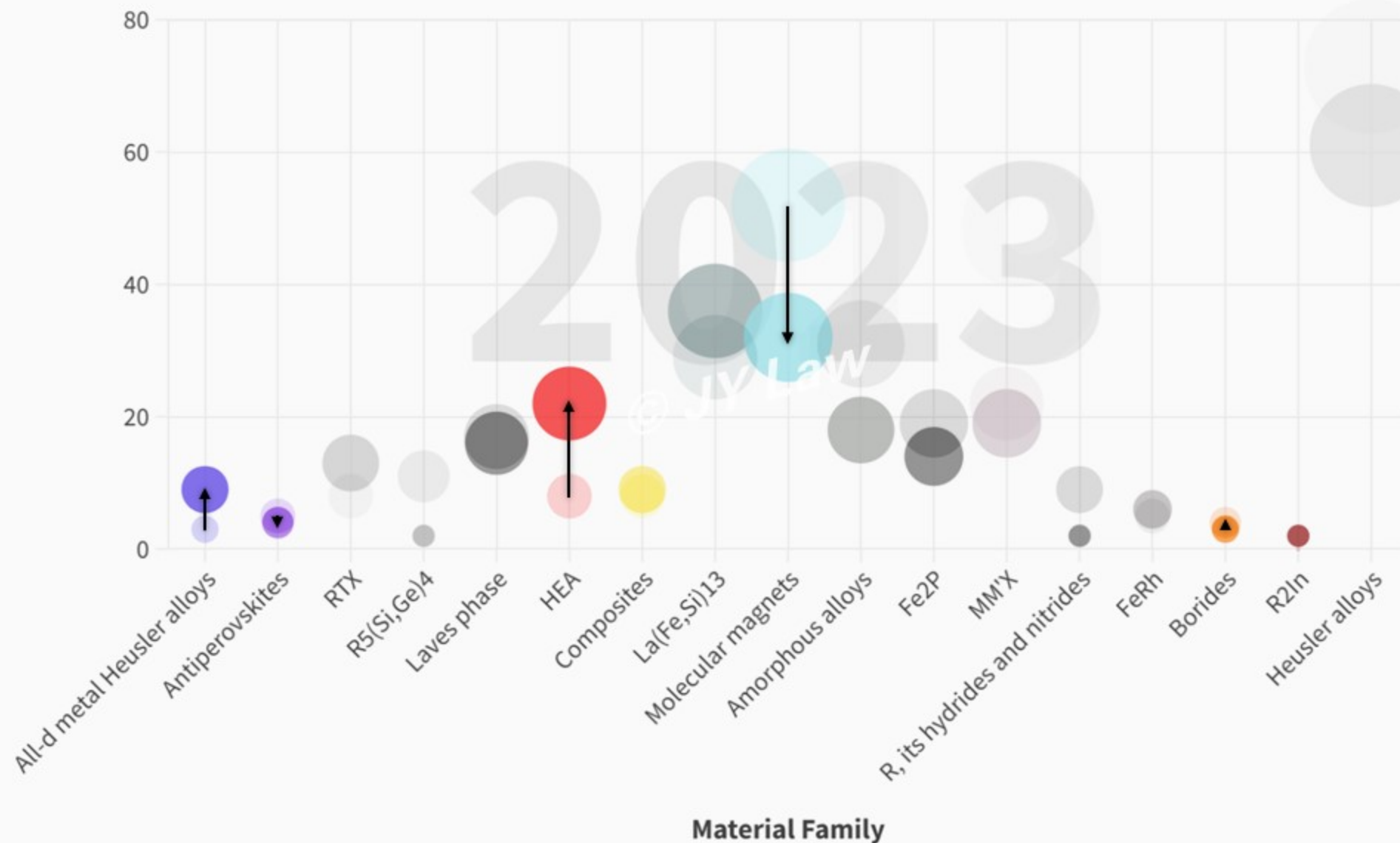


Advanced Energy Materials

Perspectives and energy applications of magnetocaloric, pyromagnetic, electrocaloric, and pyroelectric materials

DOI.10.1002/aenm.202401739

Annual Publications (2019 – 2023)



Concept of HEA

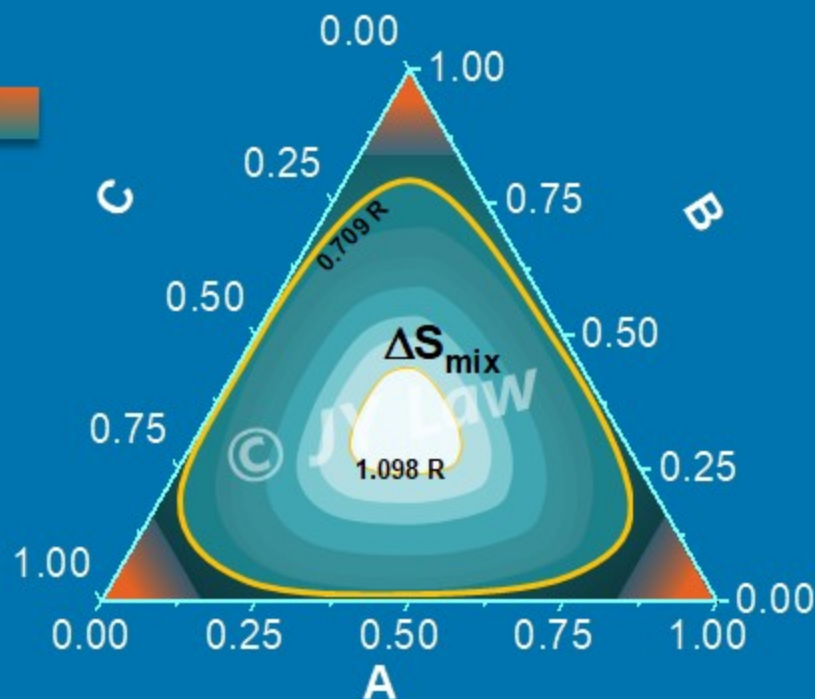
Traditional alloys or LEA



Equiatomic HEA



Image taken from J Mater Chem A 9 (2021) 663



Contour plot of ΔS_{mix} of a model ternary alloy system

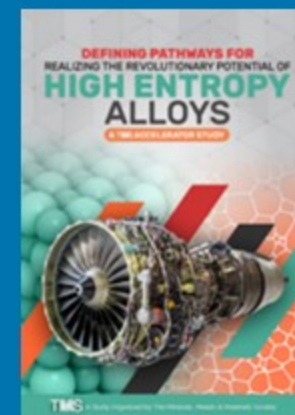
1st generation HEAs:

restricted to

- ≥ 5 principal elements
- equiatomic compositions
- single-phase metallic solid solutions

Today

HEAs have evolved to 2nd generation...



Concept of HEA

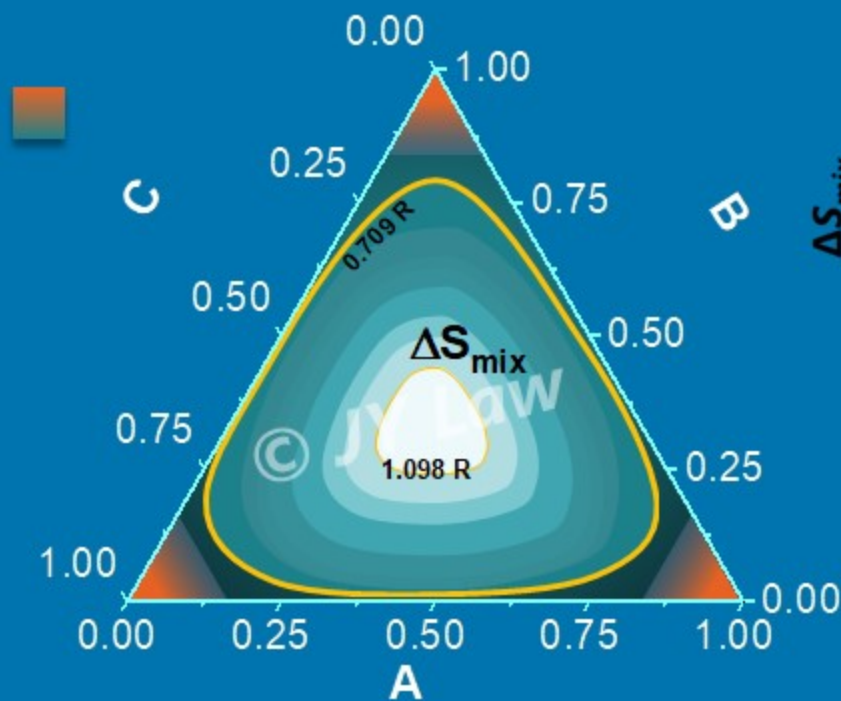
Traditional alloys or LEA

Equiatomic HEA



Image taken from J Mater Chem A 9 (2021) 663

multi principal elements



Contour plot of ΔS_{mix} of a model ternary alloy system

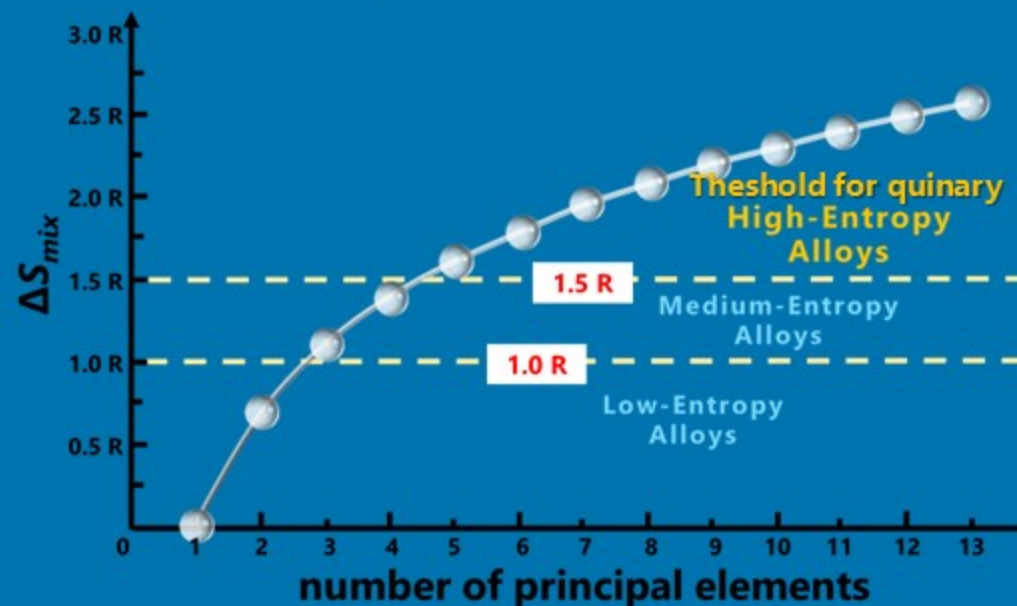
Configurational entropy of mixing

$$\Delta S_{mix} = -R \sum_{i=1}^n c_i \ln c_i$$

R = gas constant ($8.314 \text{ J mol}^{-1} \text{ K}^{-1}$)

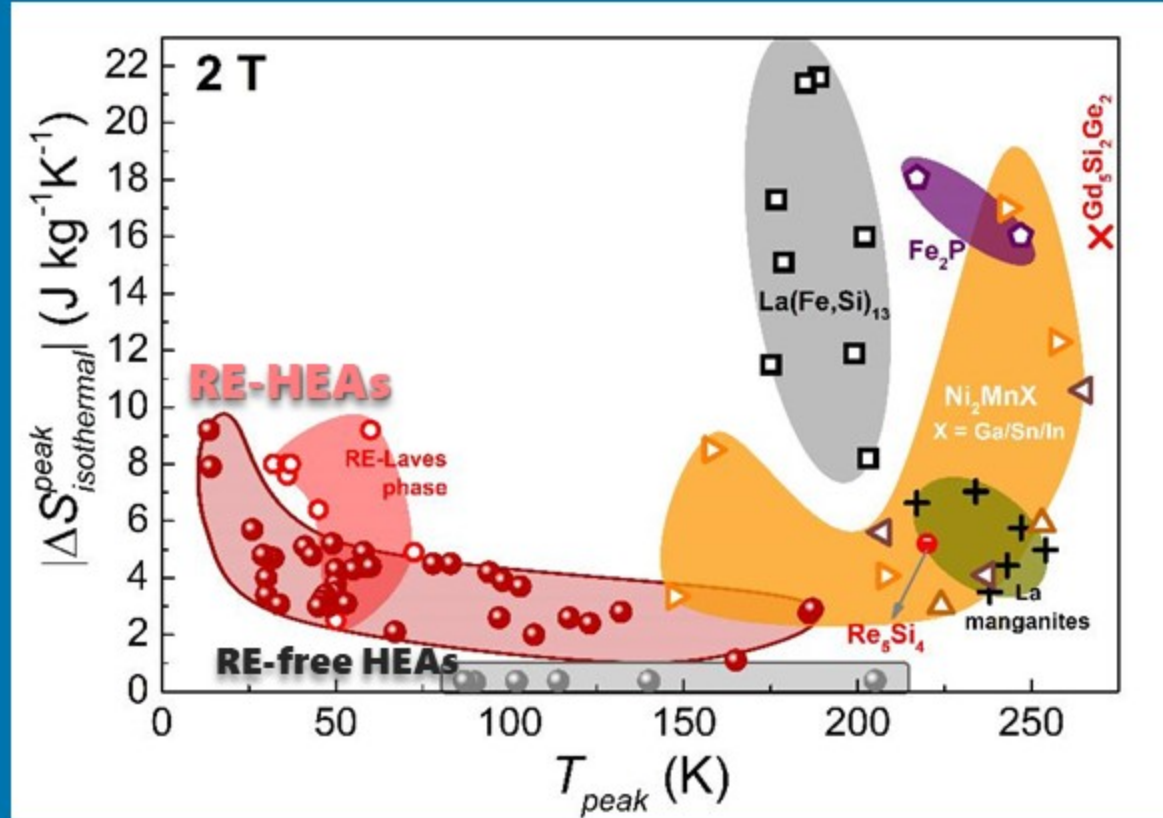
n = total # constituent elements

c_i = molar fraction of i^{th} element



HEAs are far from being competitive

compared to conventional magnetocaloric materials



HEA publications

and their different focus

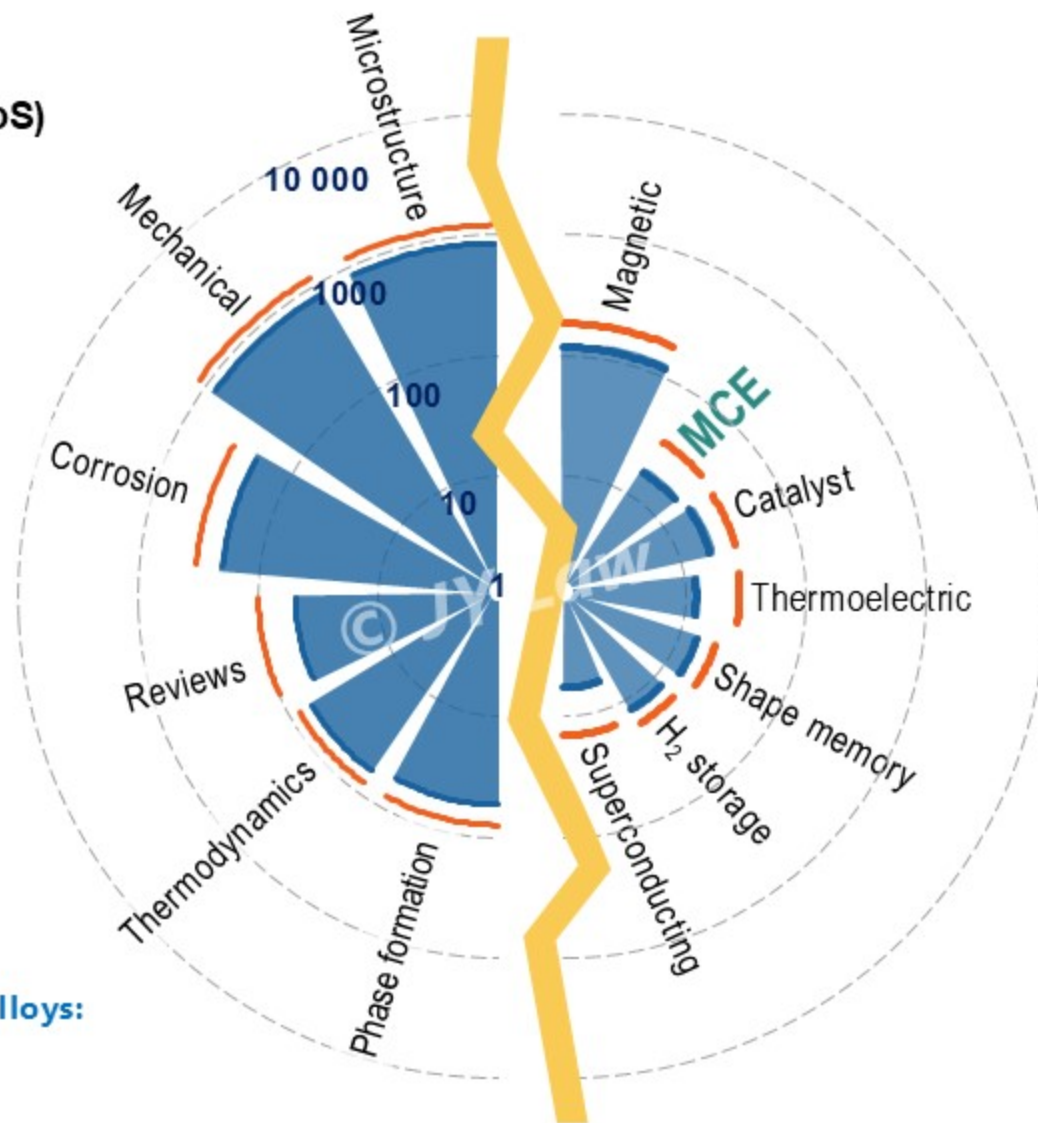


Bibliographic search (WoS)

May 2022 —

May 2021 —

structural

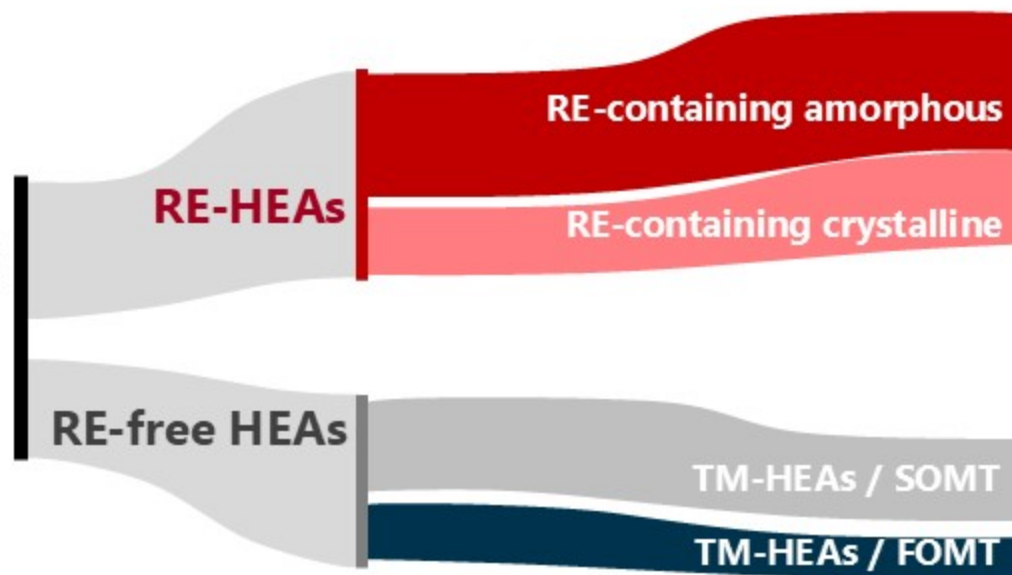


functional

JY Law, V. Franco,
Review on Magnetocaloric High-Entropy Alloys:
design and analysis methods,
J Mater Research **38** (2023) 37-51

Magnetocaloric HEAs

in the literature



Pushing the limits of magnetocaloric high-entropy alloys

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ABSTRACT

High-entropy alloys (HEAs) have become a topic of high research interest due to the excellent mechanical properties that can be found in this new type of materials. However, their functional properties are usually modest when compared to conventional materials. The discovery of high-entropy alloys with an optimal combination of mechanical and functional properties would be a leap forward in the reliability of devices that use them as functional elements. This Research Update focuses on magnetocaloric HEAs, showing that a directed search strategy allows us to improve their performance in a significant way, closing the pre-existing gap between magnetocaloric HEAs and high-performance magnetocaloric materials. Further challenges that remain in this line of research are highlighted.

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I. INTRODUCTION

Metallurgy is circa five millennia old, and for the vast majority of its past, it has mainly focused on designing new alloys by adding minor amounts of elements to one or two main constituents. Over time, the possibilities of finding new element combinations that cause a significant enhancement of the materials' properties are getting exhausted, which motivates the search for radically new approaches for alloy development. This change of philosophy arrived with the concept of high-entropy alloys (HEAs), which utilize multiple principal elements (five or more) in relatively high concentrations to form materials with a high entropy of mixing (ΔS_{mix}). HEAs encompass a vast compositional space, which provides a large window of promising opportunities for discovery of new alloys with valuable properties. In general, there are two widely accepted ways of defining HEAs based on the configurational entropy and composition requirements.^{1,2}

A. Entropy-based definition

HEAs are defined as alloys with five or more principal elements, exhibiting $\Delta S_{\text{mix}} \geq 1.5R$ regardless of being single or multiphase at room temperature, in which ΔS_{mix} is calculated as

$$\Delta S_{\text{mix}} = -R \sum_i x_i \ln x_i, \quad (1)$$

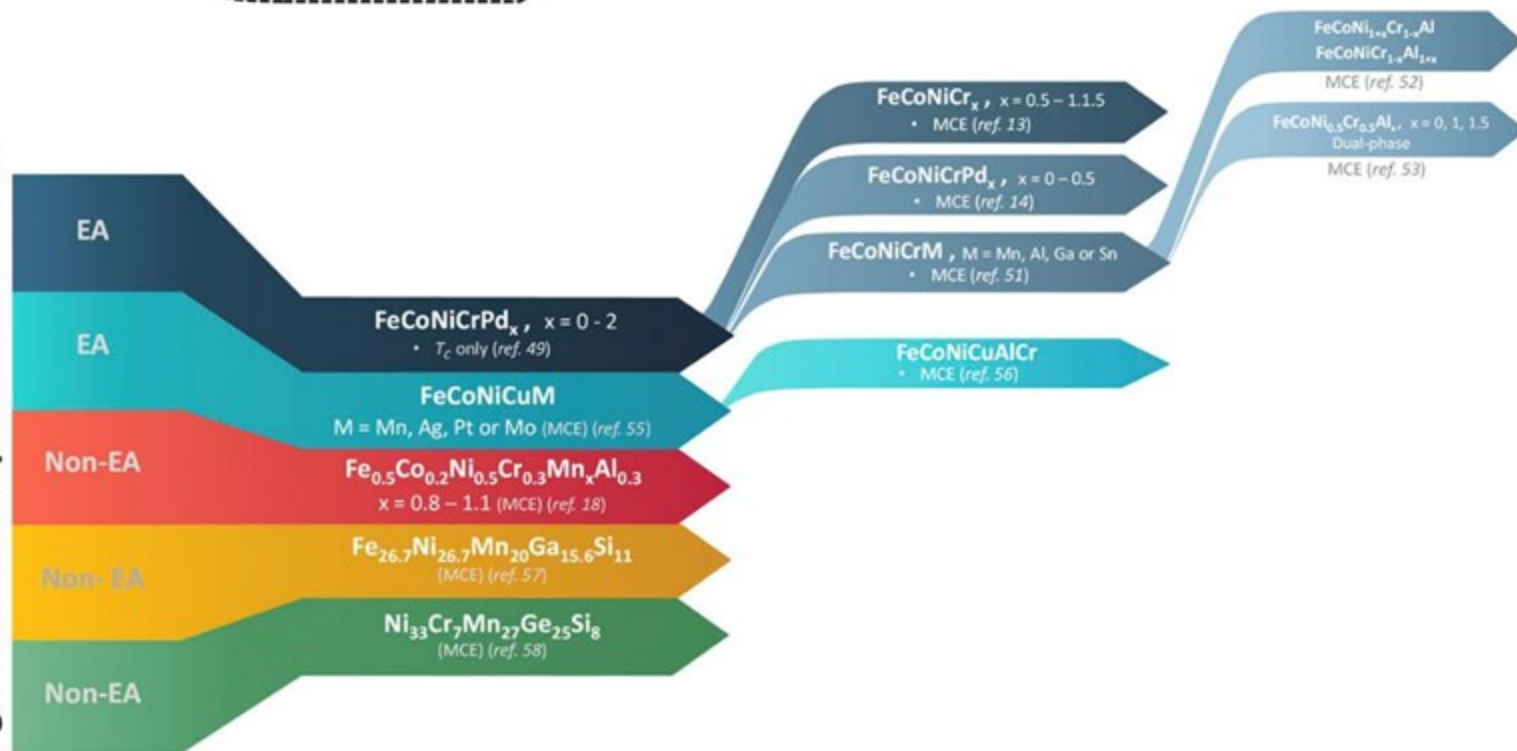
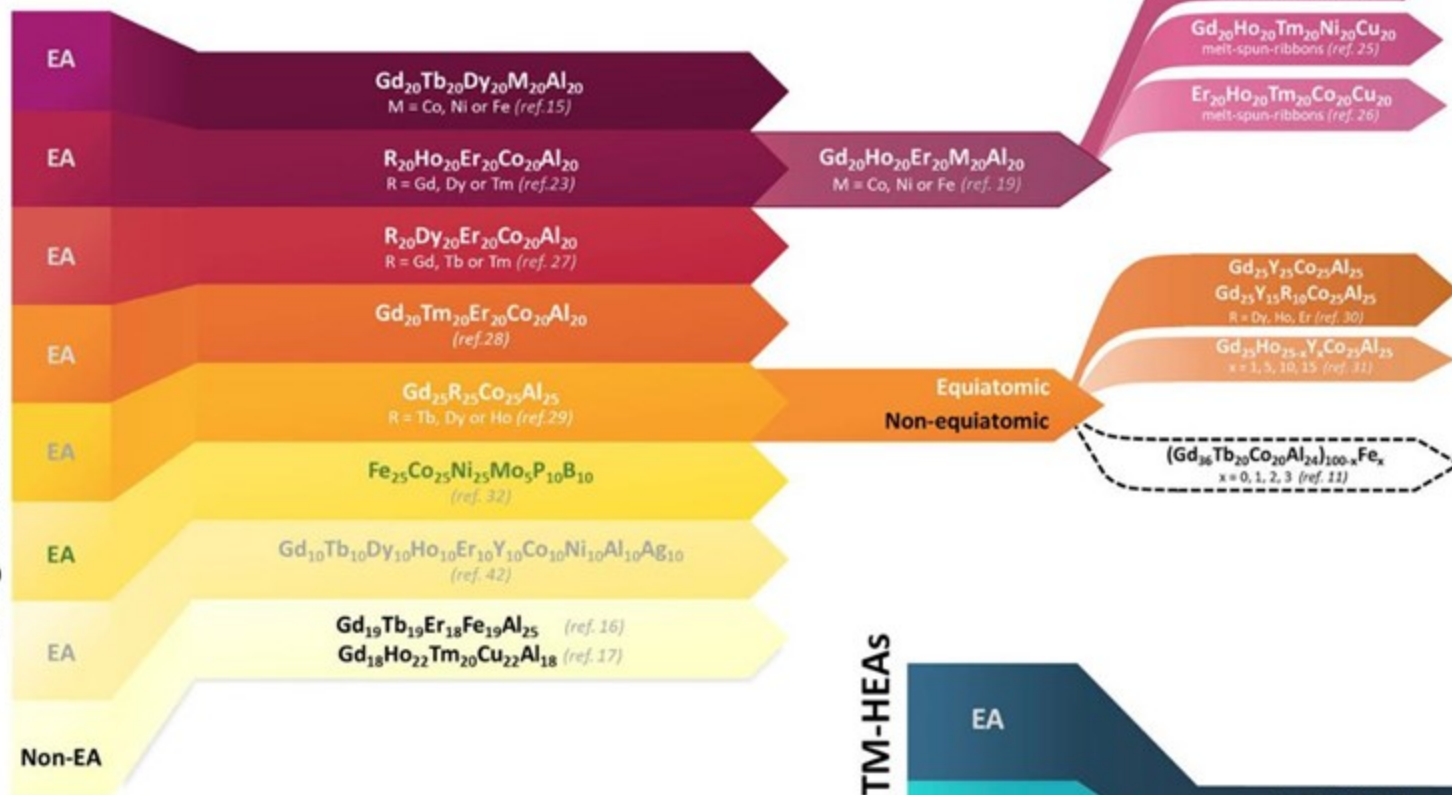
where R is the gas constant and x_i is the mole fraction of the i th element. It is worth noting that the entropy of mixing is usually simplified to exclusively consider the configurational entropy since this term dominates over the other contributions to the total entropy of mixing, which are vibrational, magnetic dipole, and electronic randomness. Figure 1 shows the various classifications of materials based on their configurational entropy values and number of principal elements, where the community preferentially considered that ΔS_{mix} of $1.5R$ is large enough to be used as the boundary between HEAs and medium-entropy alloys.

B. Composition-based definition

An alternate definition, based on the concentration of the different elements, can be summarized as

$$\begin{aligned} n_{\text{major}} &\geq 5, \quad 5 \text{ at. \%} \leq c_i \leq 35 \text{ at. \%}, \\ n_{\text{minor}} &\geq 0, \quad c_j \leq 5 \text{ at. \%}, \end{aligned}$$

where n_{major} and n_{minor} represent the number of major and minor elements, respectively. Minor elements here refer to elemental additives that are usually added to HEA systems for further tuning desired properties. c_i and c_j are the atomic percentage of i th major and j th minor elements, respectively.



Pushing the limits of magnetocaloric high-entropy alloys

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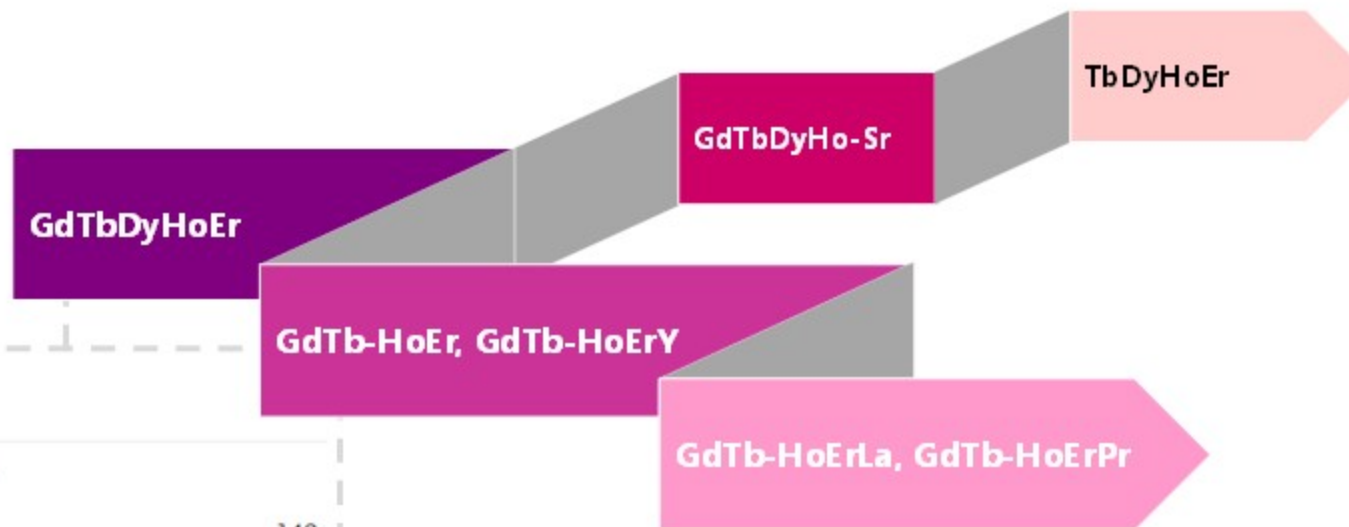
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Jia Yan Law¹ and Victorino Franco¹



Metrics Details

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Citation Indexes 149

[Scopus](#) 149

CrossRef 109

CAPTURES 167

Readers 166

[Mendeley](#) 166

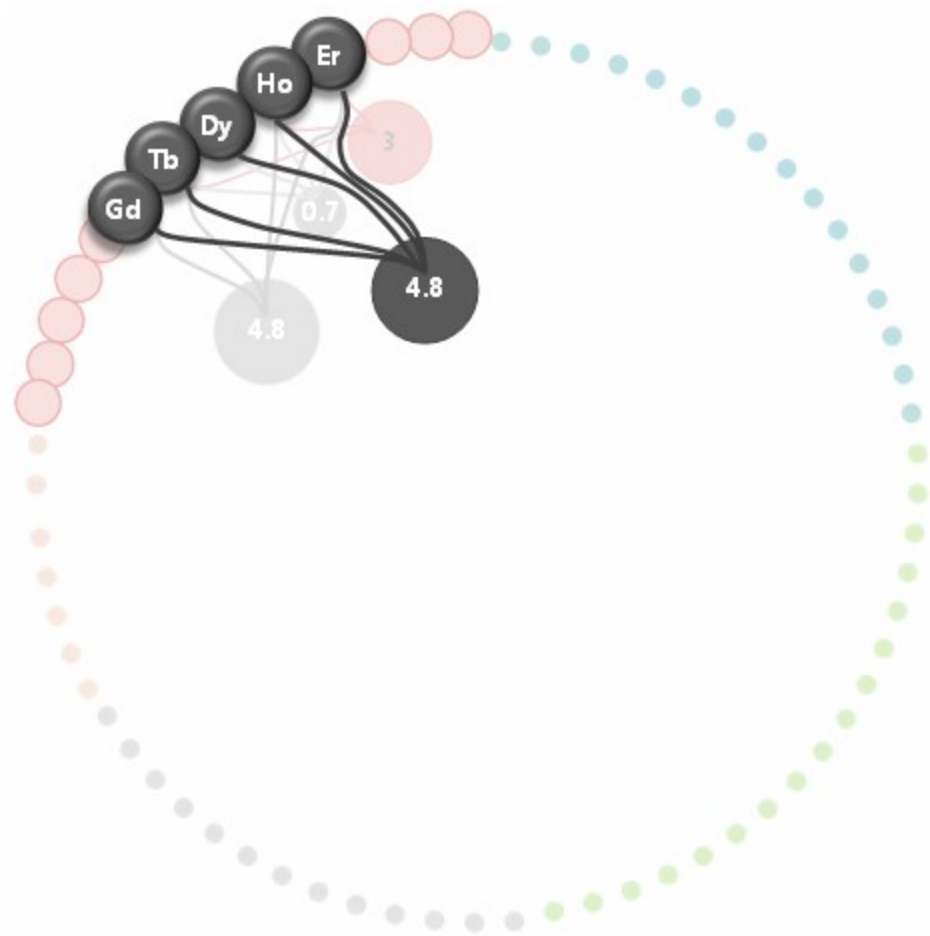
Exports-Saves 1

*EBSCO 1

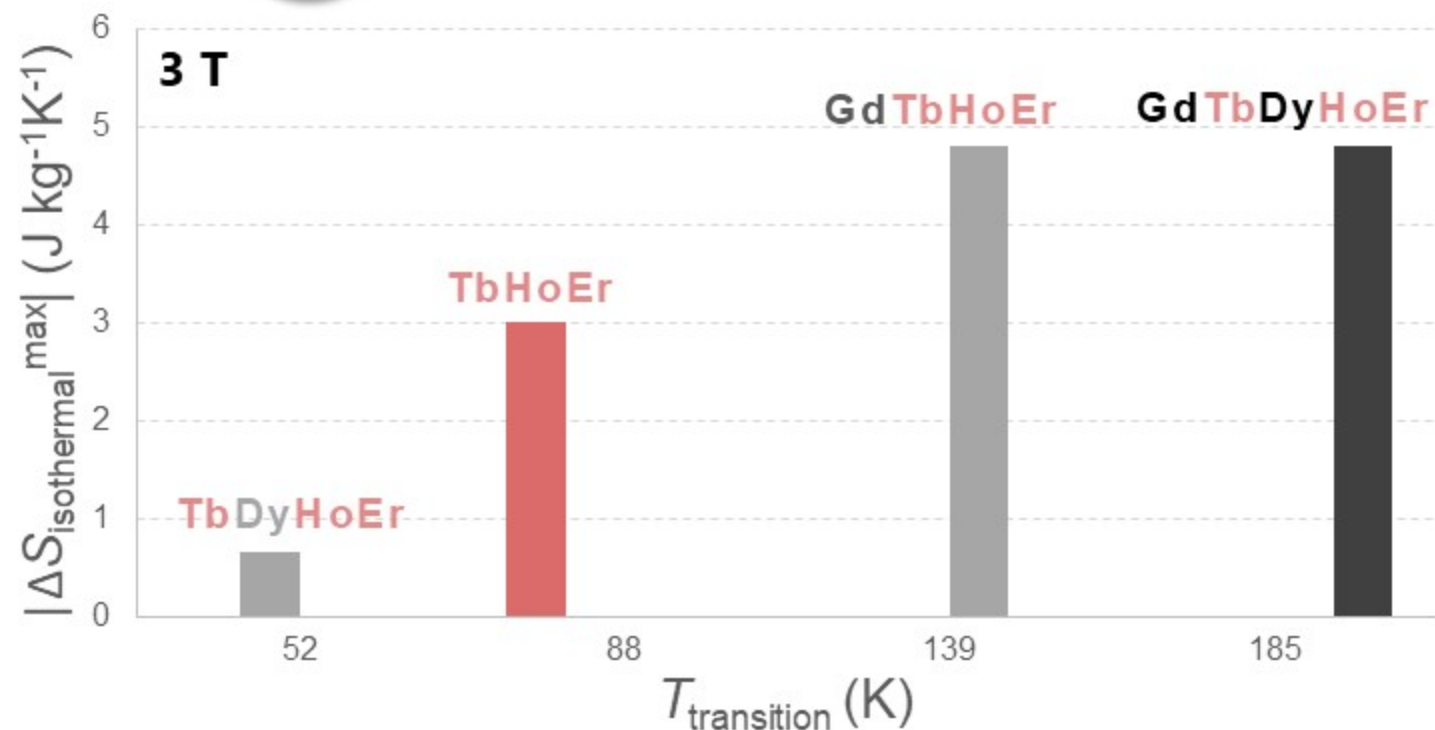
Historical data only

Search strategy

through the large HEA space



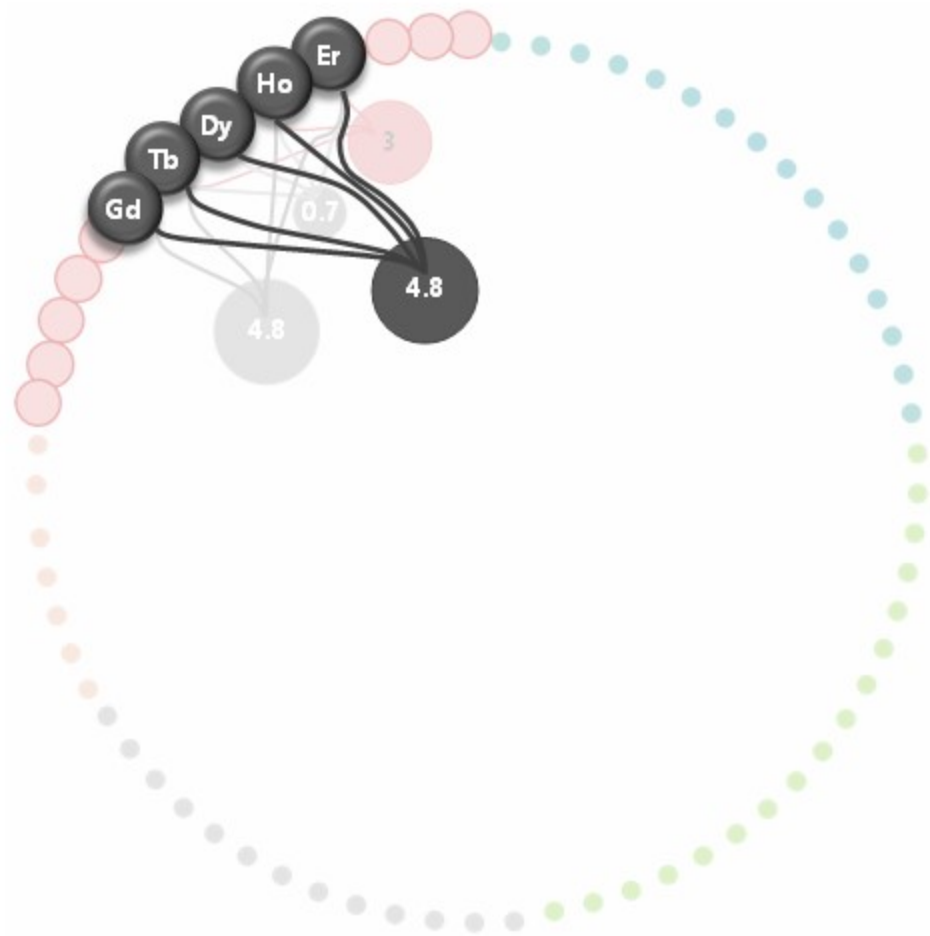
increasing number of principal elements
Rare-earth Elements



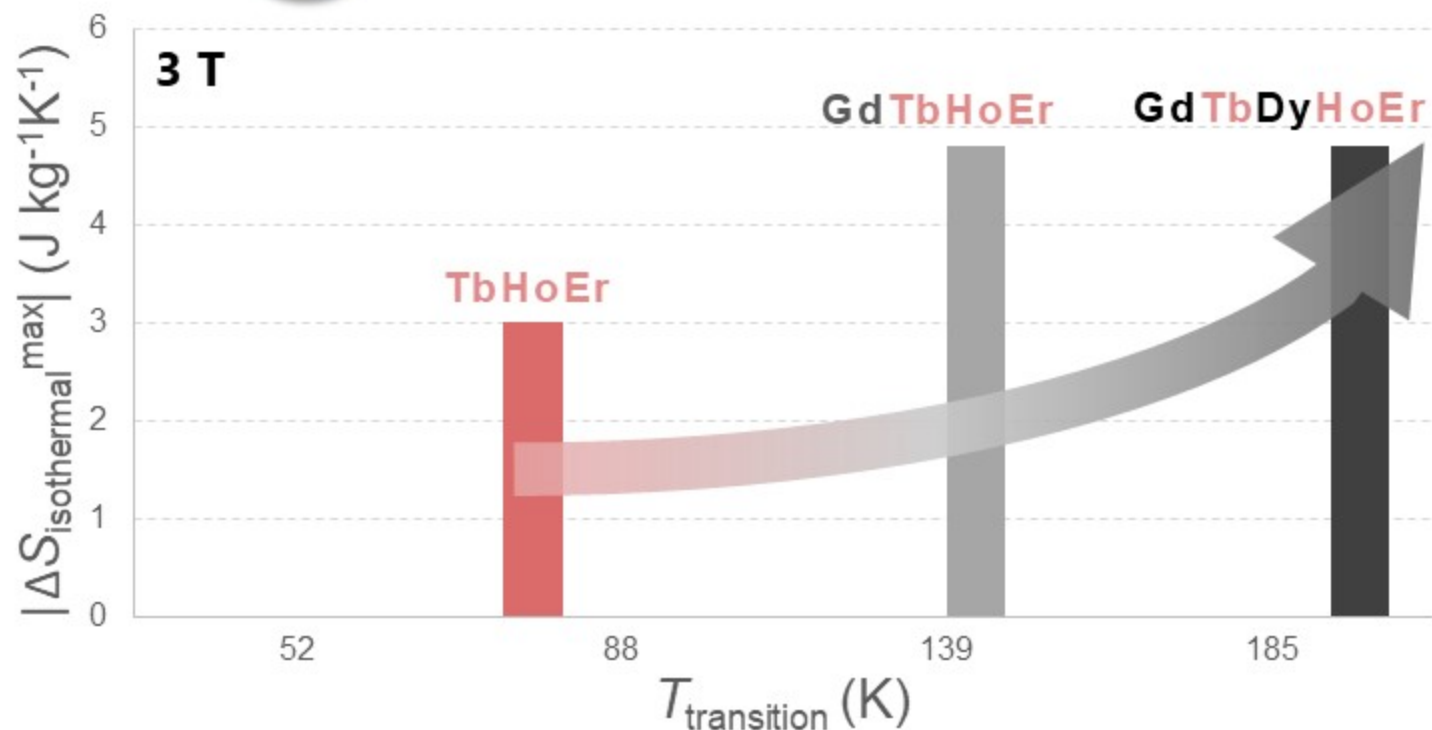
Data collected from
Y. Yuan et al., Acta Mater 125 (2017) 481

Search strategy

through the large HEA space



increasing number of principal elements
Rare-earth Elements



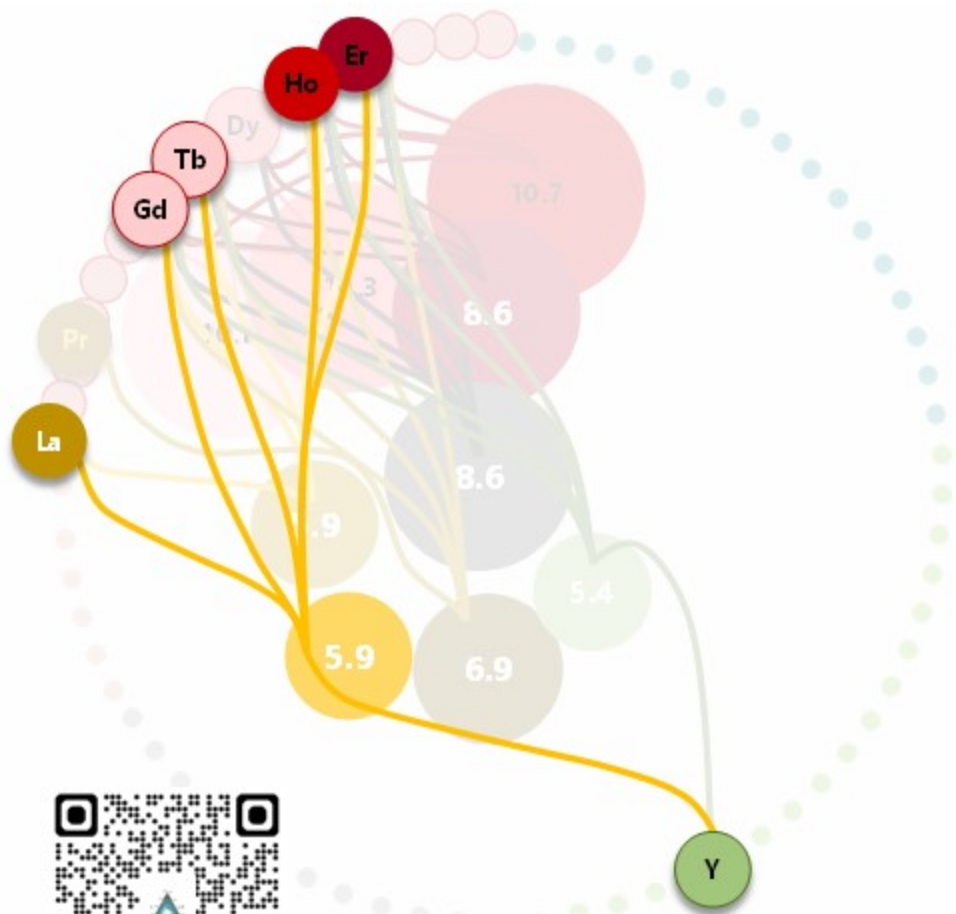
Data collected from
Y. Yuan et al., Acta Mater 125 (2017) 481

Search strategy

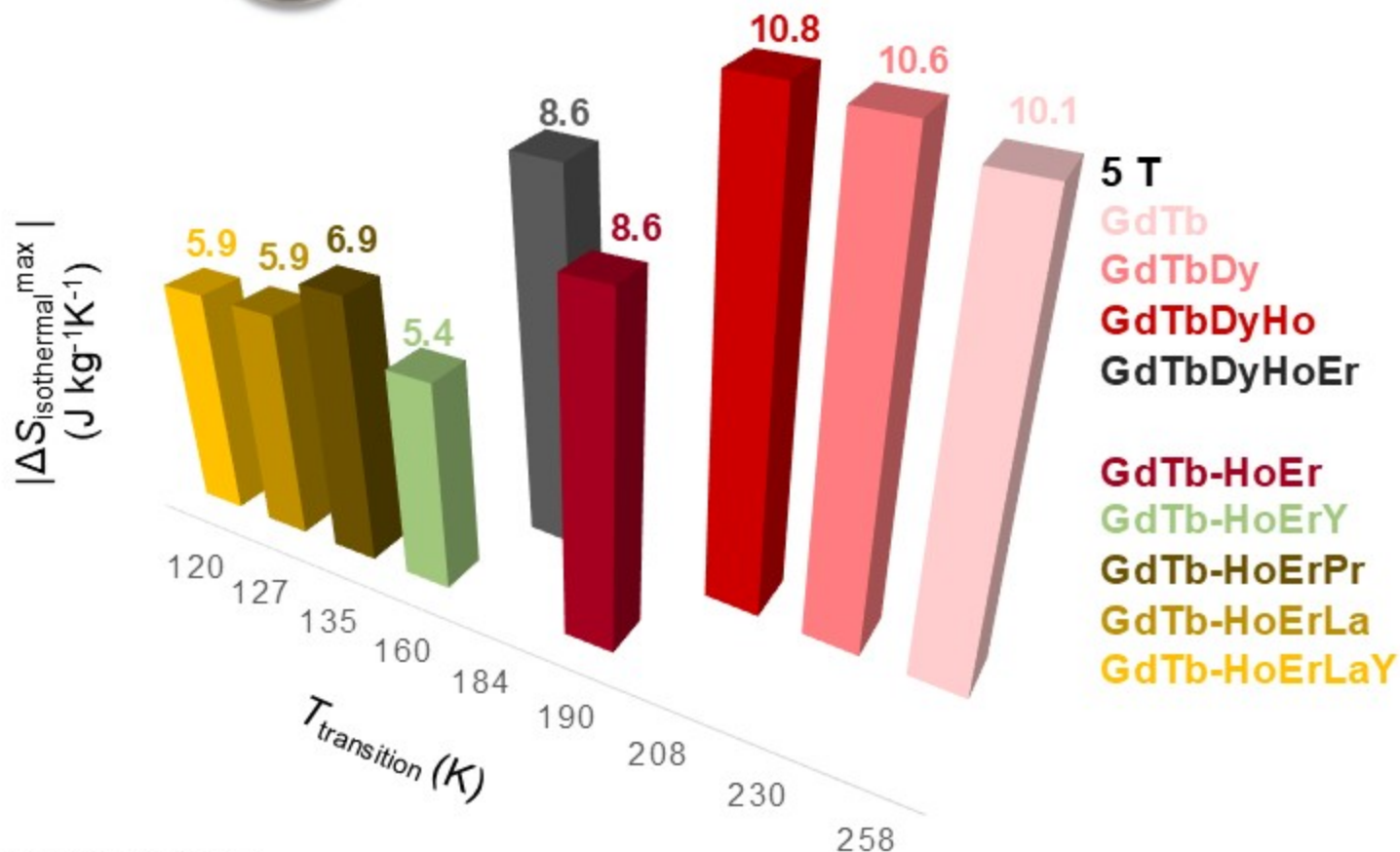
through the large HEA space



increasing number of principal elements



JY Law, V. Franco,
Review on Magnetocaloric High-Entropy Alloys:
design and analysis methods,
J Mater Research **38** (2023) 37-51



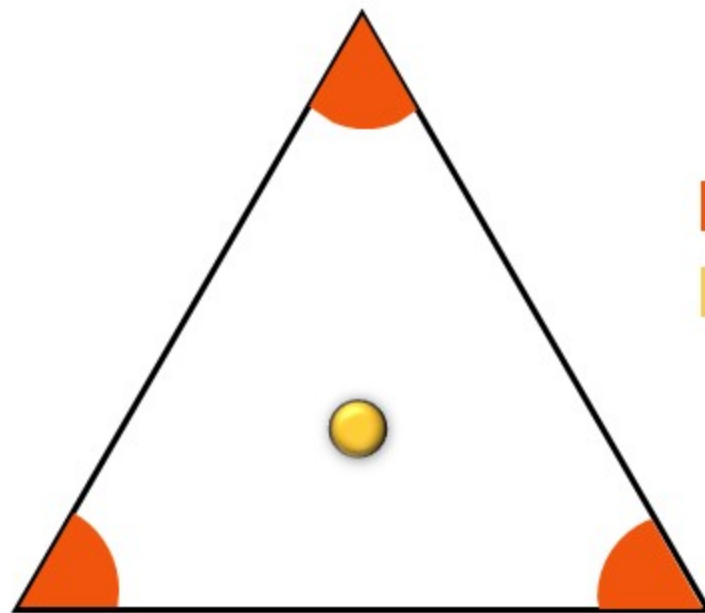
Data collected from
SF Lu et al, *J Mater Sci: Mater Electron* 32 (2021) 10919; SF Lu et al, *JALCOM* 874 (2021) 159918

Search strategy

through the large HEA space



increasing number of principal elements



 Traditional alloys

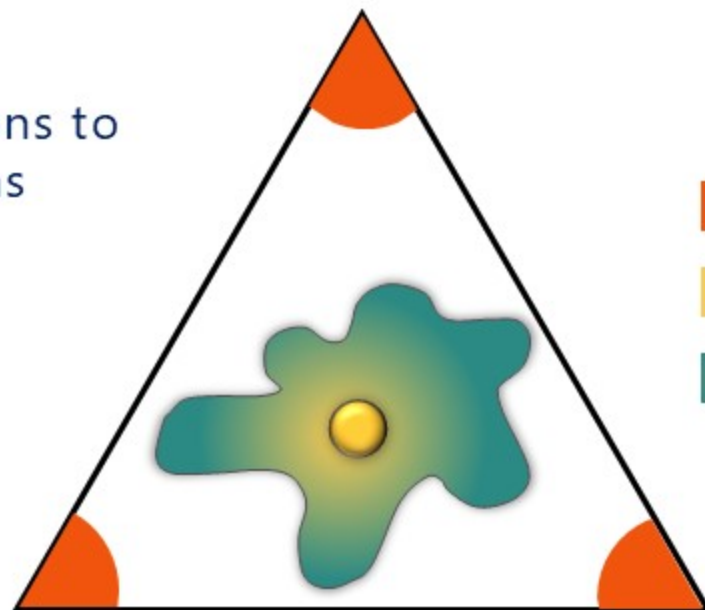
 Equiatomic HEA

Search strategy

through the large HEA space



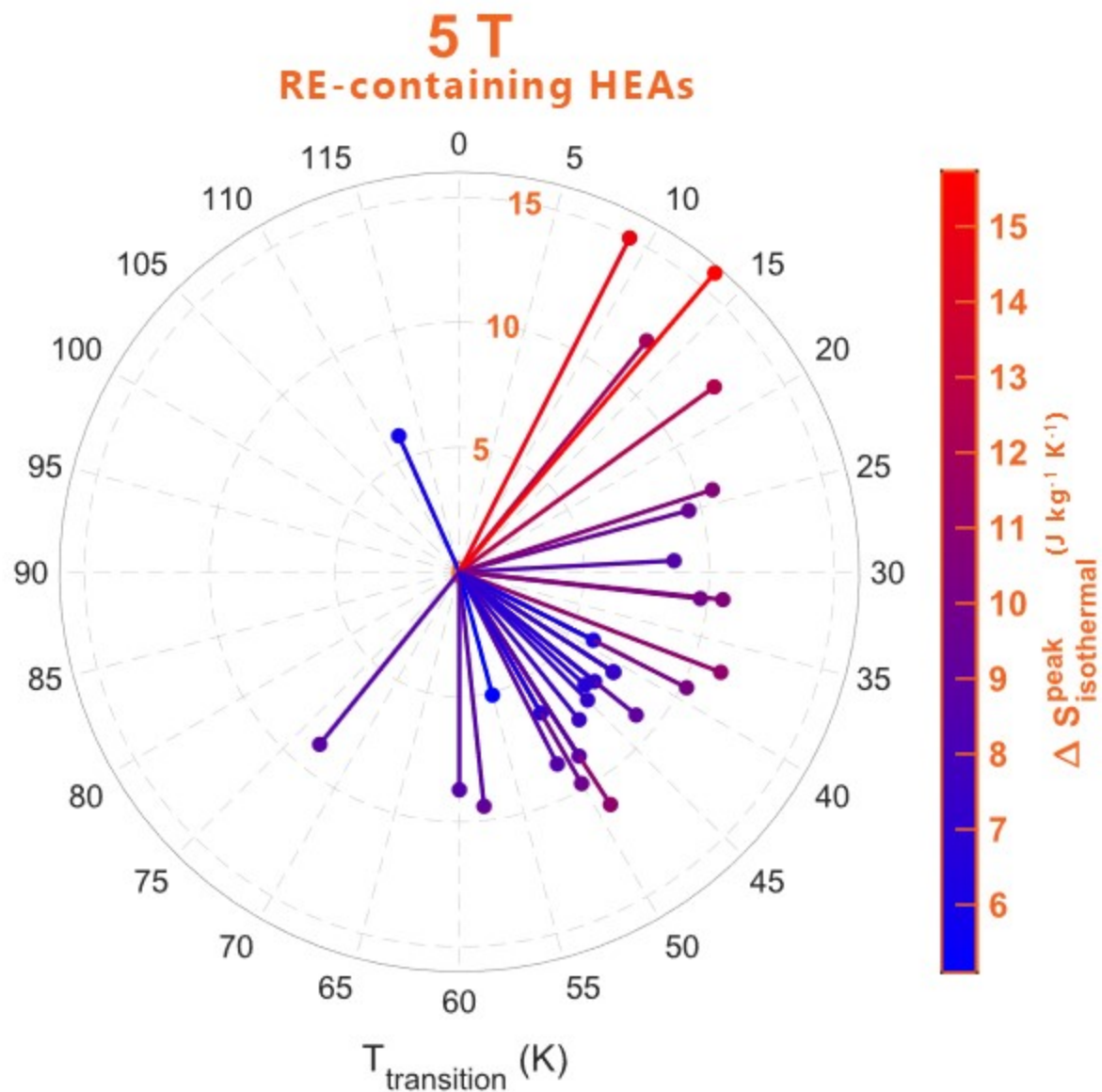
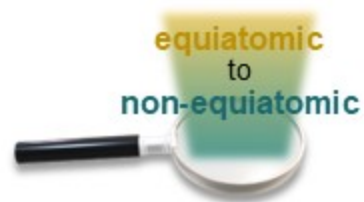
extending from
equiatomic compositions to
non-equiatomic regions



- Traditional alloys
- Equiatomic HEA
- Non-equiatomic HEA

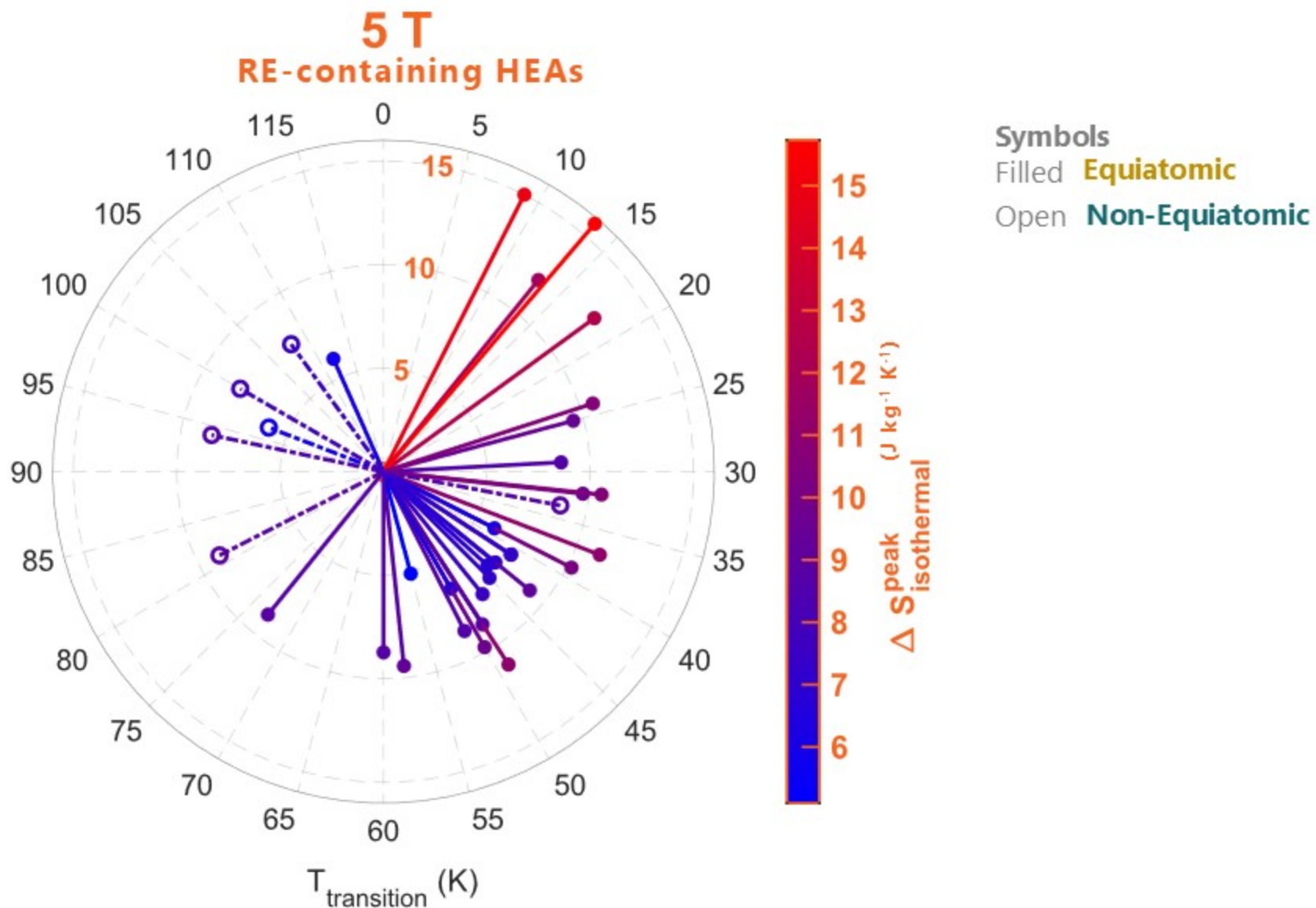
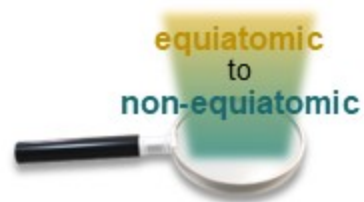
Search strategy

through the large HEA space



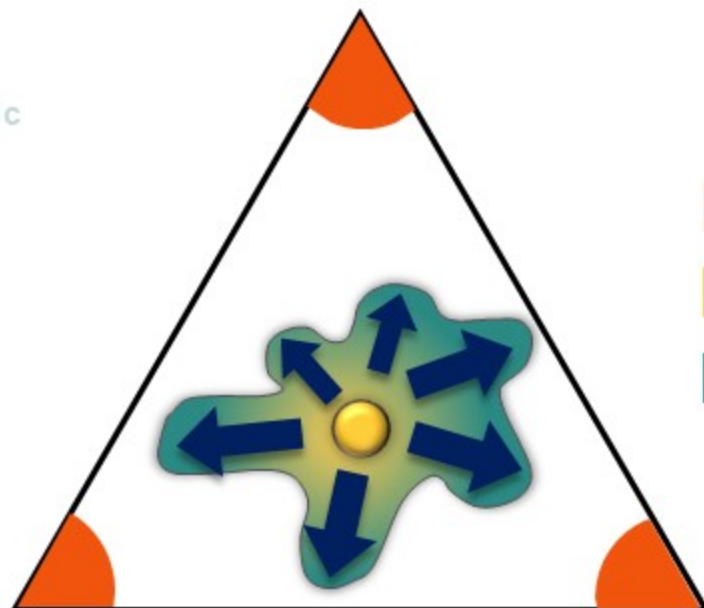
Search strategy

through the large HEA space



Search strategy

through the large HEA space

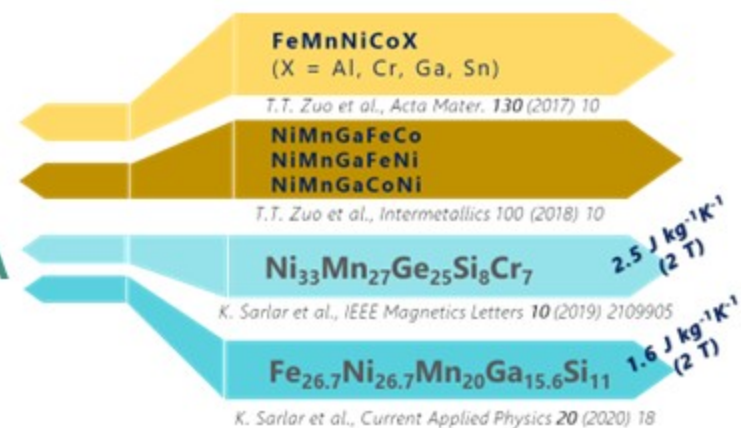


Traditional alloys

Equiatomic HEA

Non-equiatomic HEA

SOPT

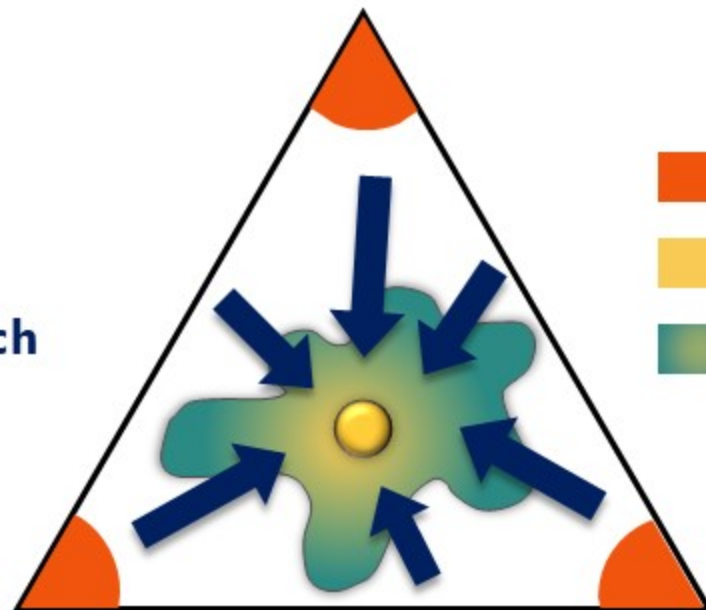


Search strategy

through the large HEA space



targeted property search



-  **Traditional alloys**
-  **Equiatomic HEA**
-  **Non-equiatomic HEA**



targeted property search



Home > Rare Metals > Article

Frontiers in high entropy alloys and high entropy functional materials

Review | Published: 28 August 2024

Volume 43, pages 4639–4776, (2024) [Cite this article](#)

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Rare Metals

[Aims and scope](#) →

[Submit manuscript](#) →

3 High-entropy alloys as cutting-edge functional materials

3.2.4 Third-generation magnetocaloric HEAs

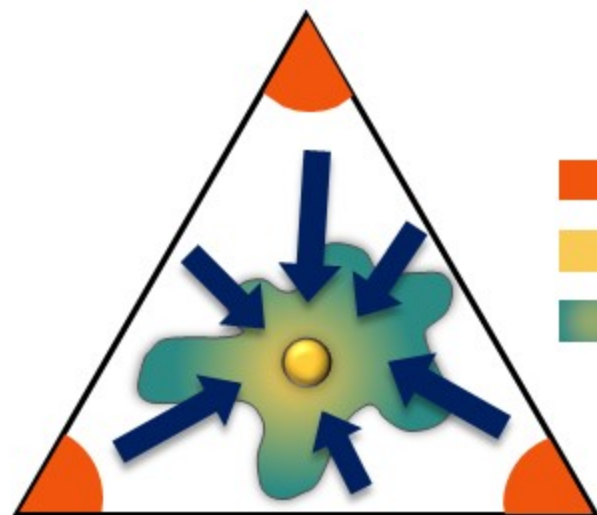
Compared to conventional magnetocaloric materials, the second-generation magnetocaloric HEAs offer an enhanced temperature span of MCE due to the broadened magnetic phase transition, but at the expense of the magnitudes of ΔS_{iso} and ΔT_{ad} . Law et al. [604, 605] proposed a property-directed strategy for the design of third-generation magnetocaloric HEAs. It starts from conventional magnetocaloric materials with giant MCE (i.e., compositions showing a first-order magnetostructural transition) and subsequently turns them into the HEA category. This search strategy has been successfully demonstrated in MM'X-based magnetocaloric HEAs by Law et al. in 2021 [628]. They obtained a ΔS_{iso} of $7.3 \text{ J} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$ in $\Delta \mu_0 H = 2.5 \text{ T}$ in $\text{Mn}_{22.3}\text{Fe}_{22.2}\text{Ni}_{22.2}\text{Ge}_{16.65}\text{Si}_{16.65}$ HEA, which was further increased to $13 \text{ J} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$ in $\Delta \mu_0 H = 2.5 \text{ T}$ by compositional optimization in the HEA space [629]. Recently, Zheng et al. [630] also reported a large ΔS_{iso} of $48.5 \text{ J} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$ under $\Delta \mu_0 H = 5 \text{ T}$ in $(\text{MnNi})_{0.6}\text{Si}_{0.62}(\text{FeCo})_{0.4}\text{Ge}_{0.38}$ HEAs. Additionally, Guo et al. [631] claimed that the design of high-entropy composition can reduce the undesirable thermal hysteresis (ΔT_{hys}) of MM'X materials. They obtained a ΔT_{hys} as low as 4.3 K in $\text{Mn}_{1.75}\text{Fe}_{0.25}\text{CoNiGe}_{1.6}\text{Si}_{0.4}$ HEA alloy, which provides a new strategy to tackle the phase irreversibility for magnetocaloric materials with a first-order magnetostructural transition.

Search strategy

through the large HEA space



targeted property search



- Traditional alloys
- Equiatomict HEA
- Non-equiatomict HEA



Starting composition

selection based on known alloy with desired behavior



Tune towards HEA region

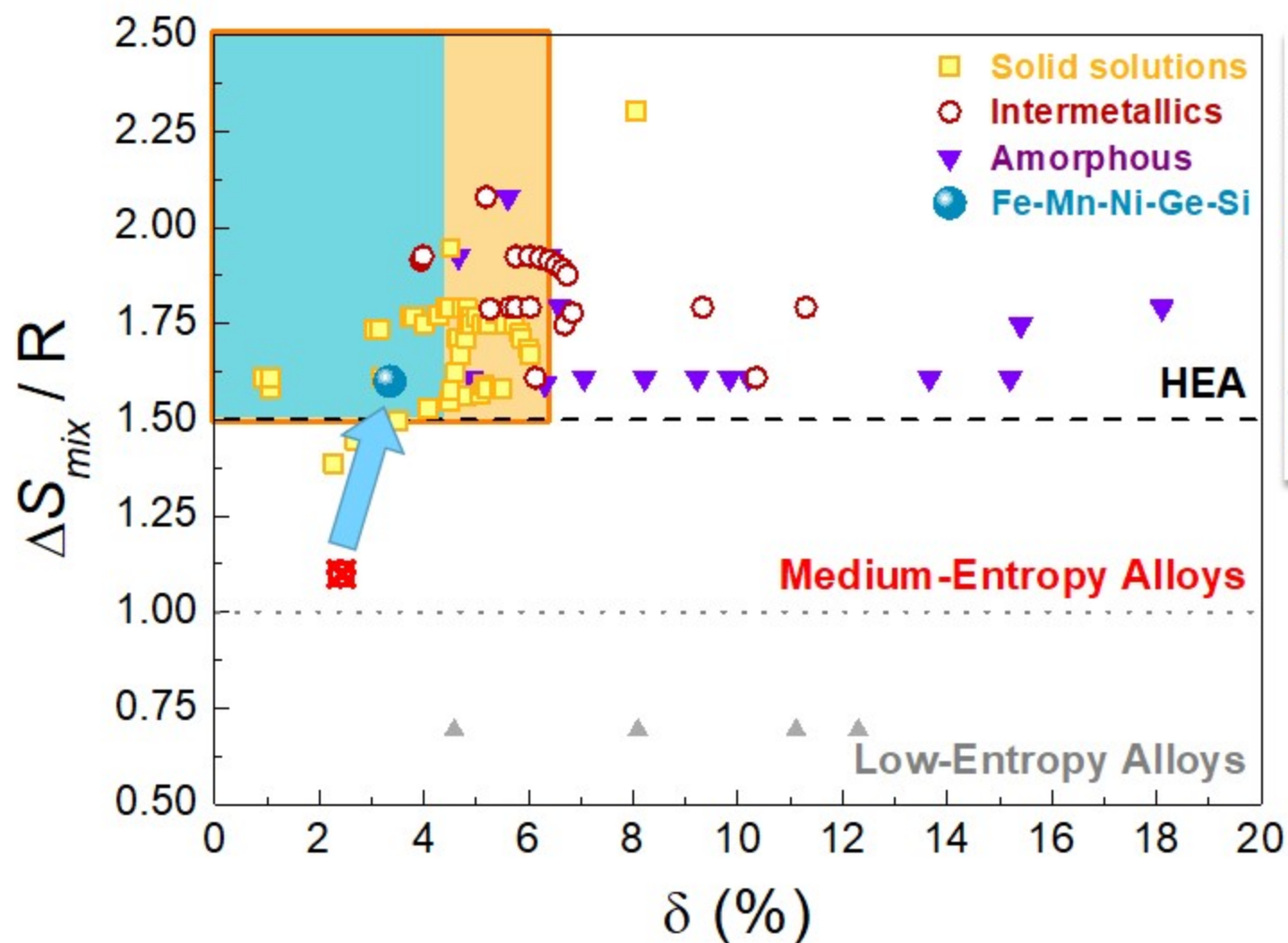
considering elements with chemical compatibility



Maintain the stoichiometry

Search strategy

in the vast HEA space



Journal of Alloys and Compounds 855 (2021) 157424

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Journal of Alloys and Compounds

journal homepage: <http://www.elsevier.com/locate/jalcom>

MnFeNiGeSi high-entropy alloy with large magnetocaloric effect

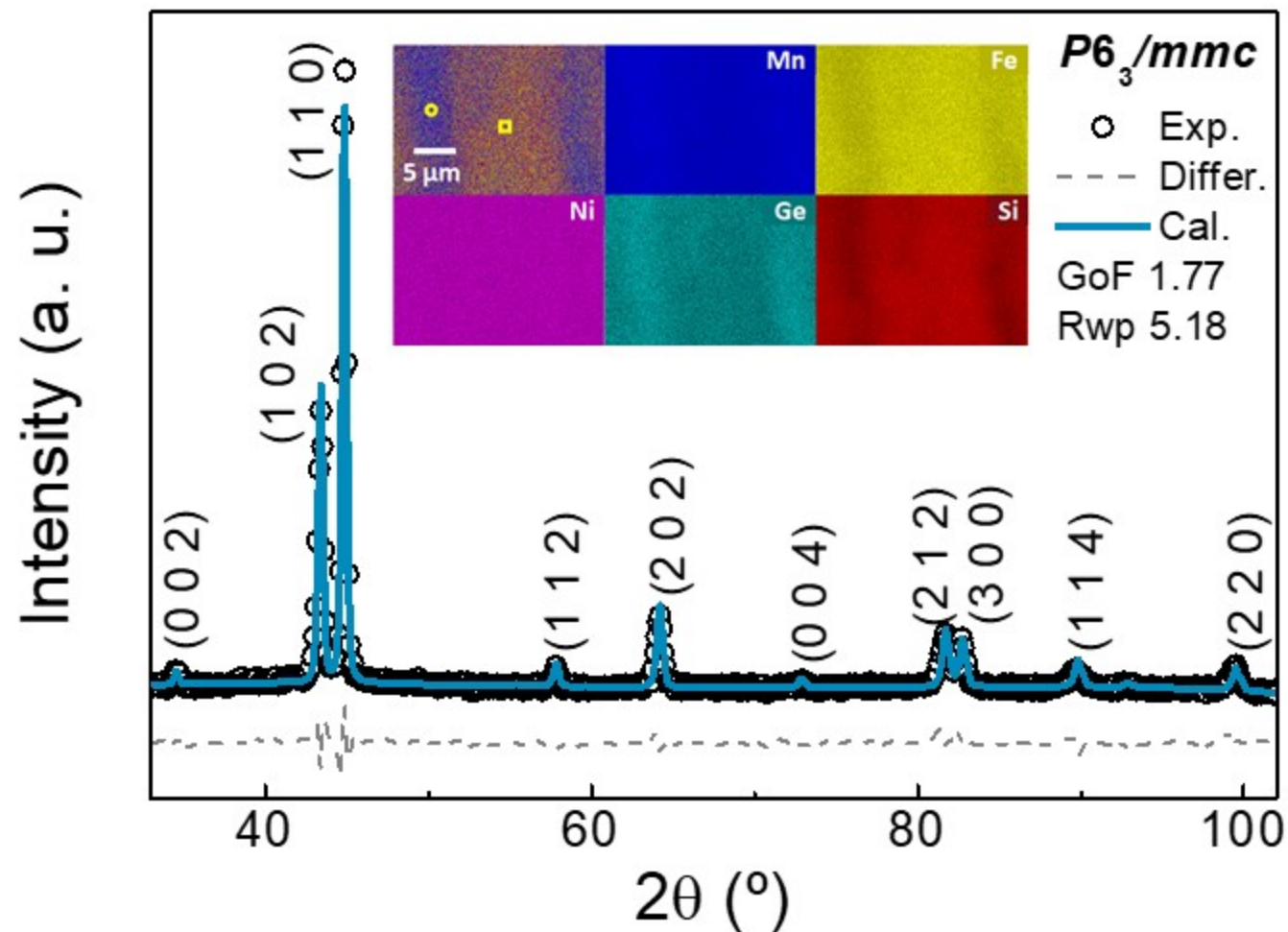
Jia Yan Law^{a, **}, Luis M. Moreno-Ramírez^a, Álvaro Díaz-García^a, Andrés Martín-Cid^b, Shintaro Kobayashi^b, Shogo Kawaguchi^b, Tetsuya Nakamura^b, Victorino Franco^{a, *}

^a Department of Condensed Matter Physics, ICMS-CSIC, Universidad de Sevilla, P.O. Box 1065, 41080, Sevilla, Spain

^b SPring-8, Japan Synchrotron Radiation Research Institute, 1-1-1 Kouto, Sayo, Japan

Fe-Mn-Ni-Ge-Si

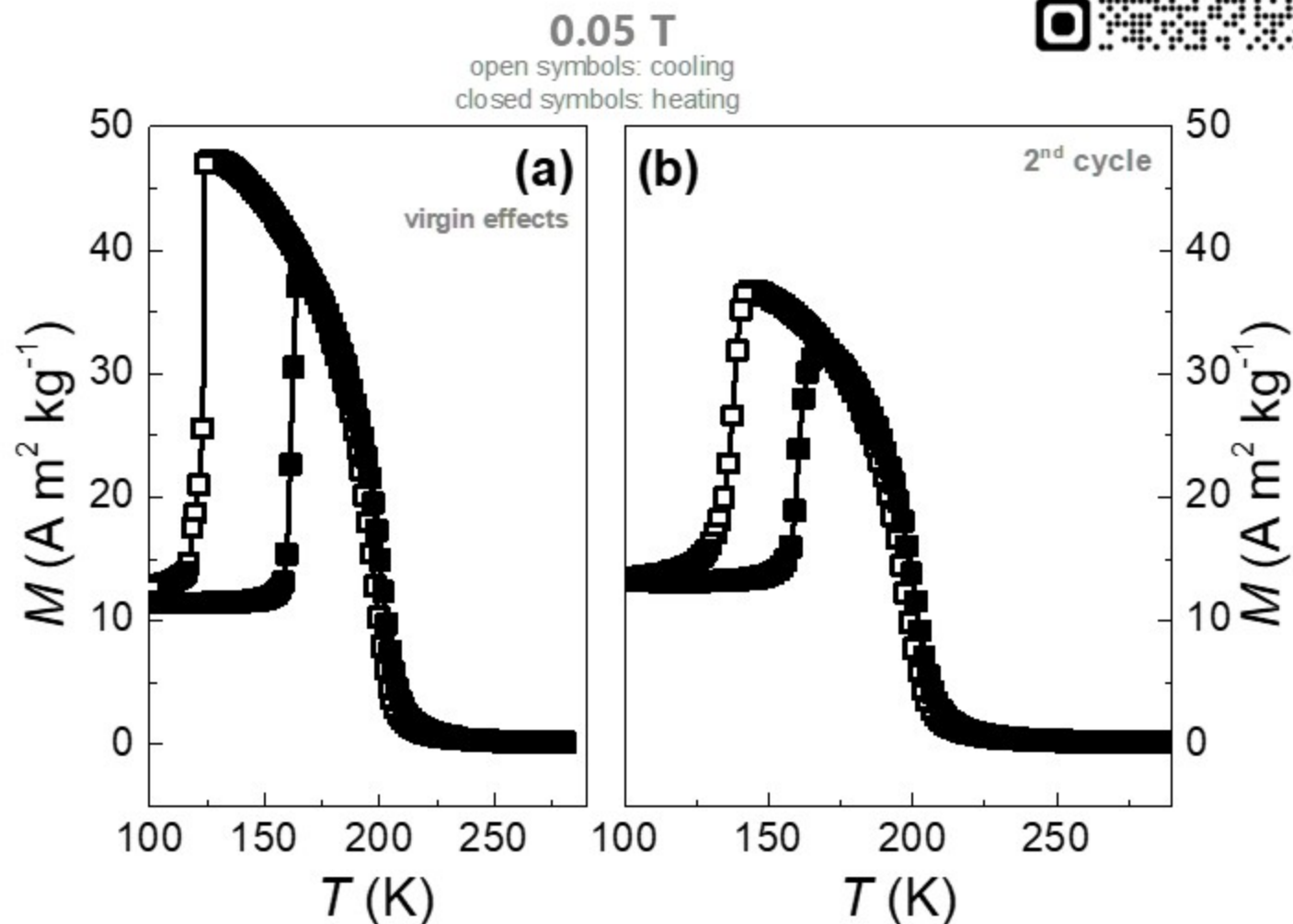
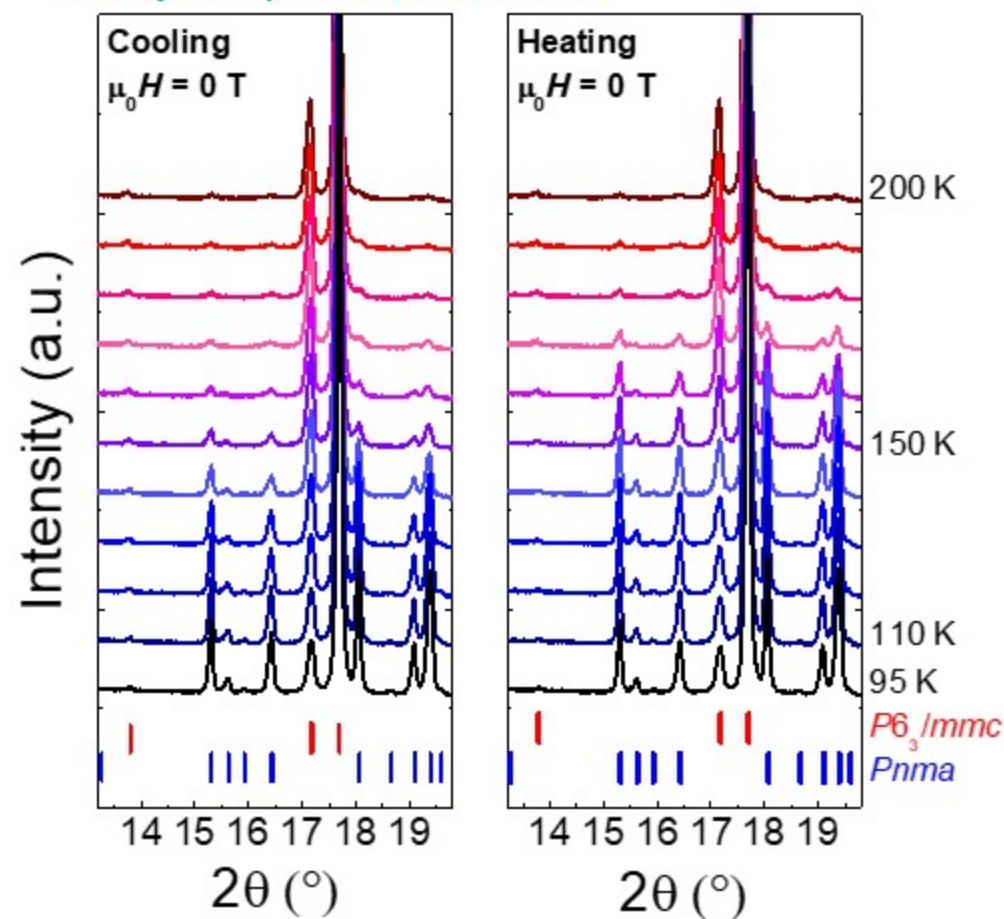
At room temperature



Fe-Mn-Ni-Ge-Si

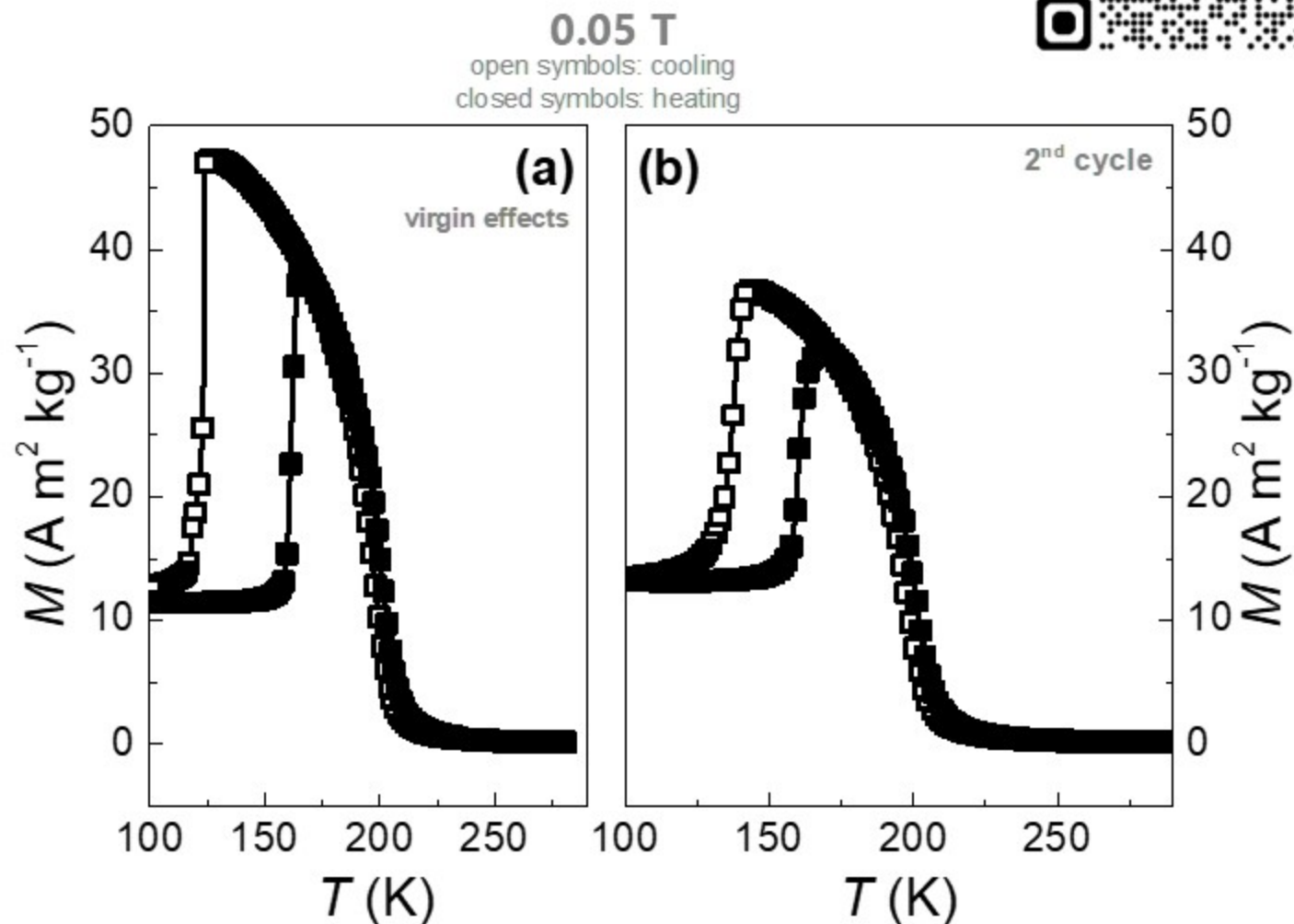
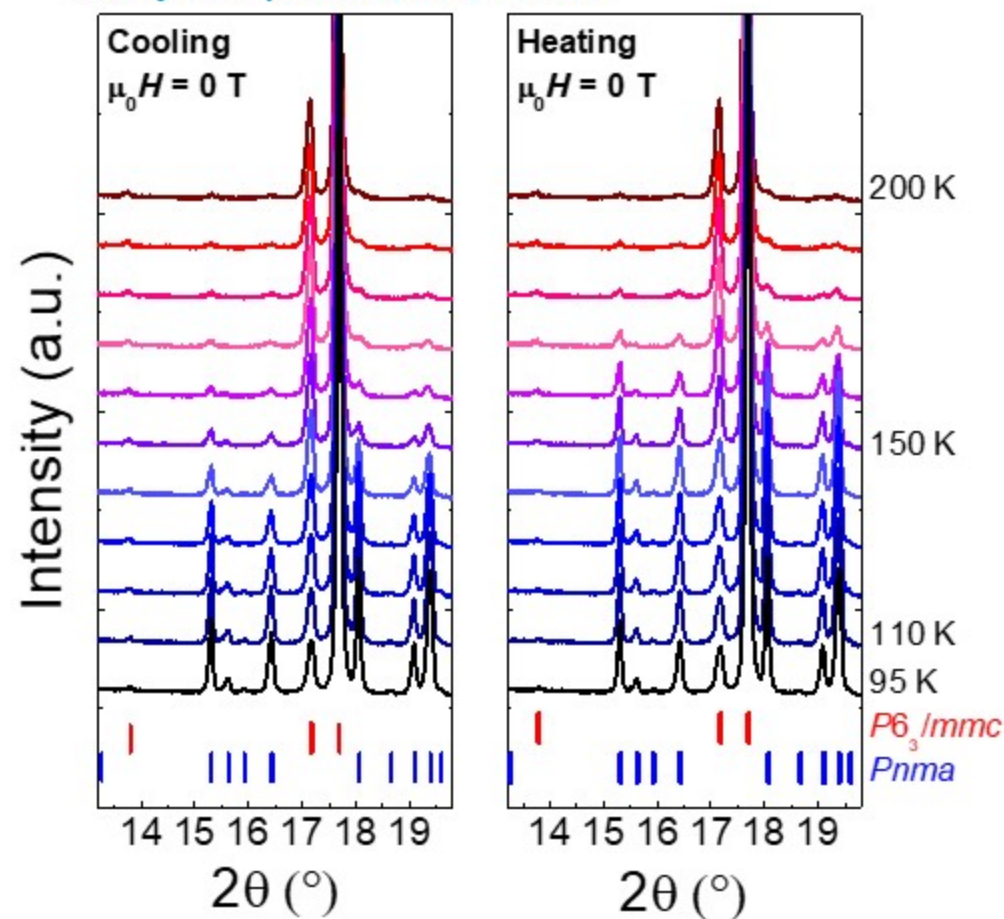
Upon heating and cooling

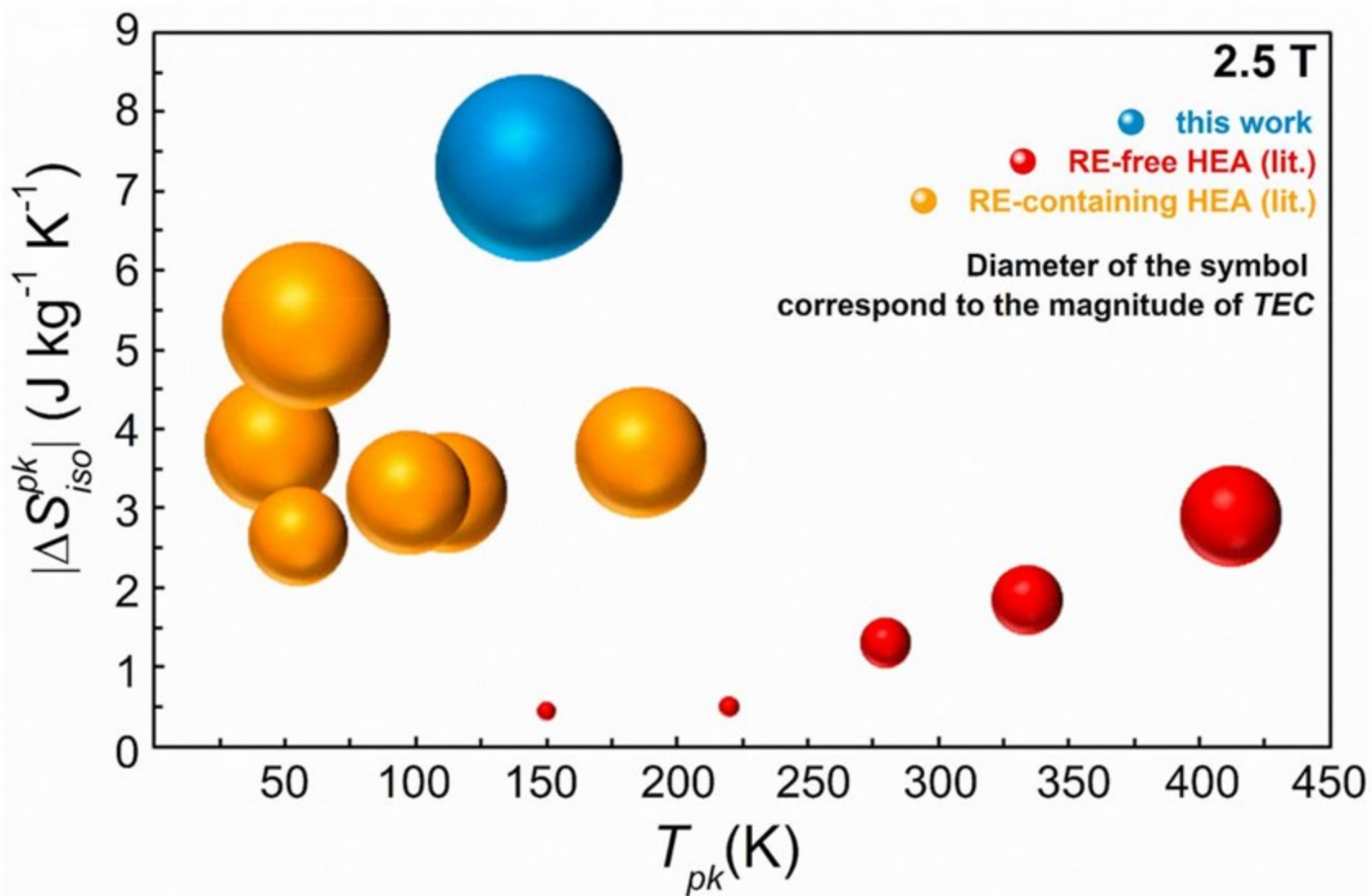
JY Law, L.M. Moreno-Ramírez, Á. Díaz-García, A. Martín-Cid,
S. Kobayashi, S. Kawaguchi, T. Nakamura and V. Franco,
J Alloys Compds 855 (2021) 157424



Phase transition temperatures in good agreement magnetostructural

JY Law, L.M. Moreno-Ramírez, Á. Díaz-García, A. Martín-Cid,
S. Kobayashi, S. Kawaguchi, T. Nakamura and V. Franco,
J Alloys Compds 855 (2021) 157424



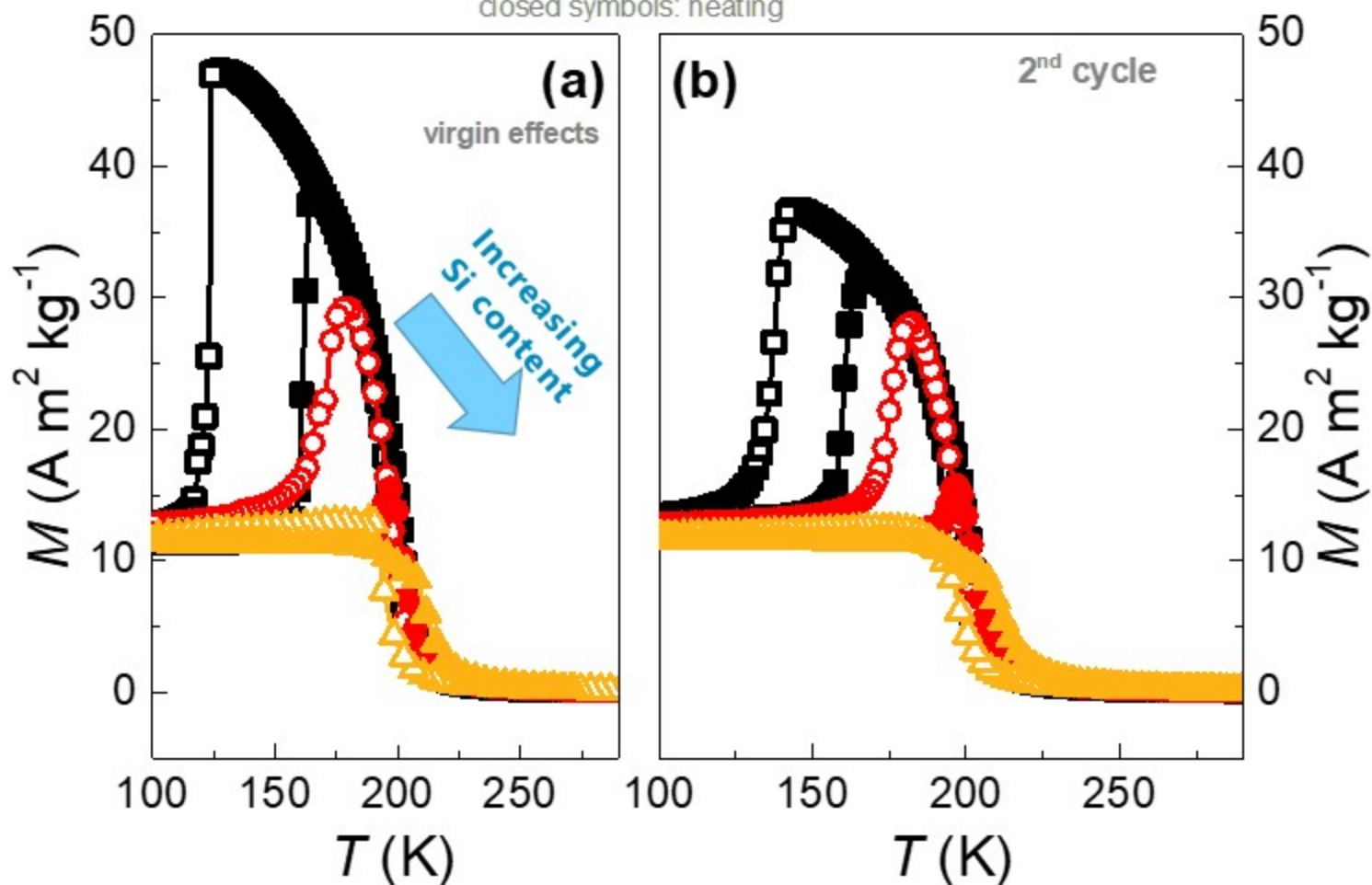


Could that go further?

series (varying Si content)

0.05 T

open symbols: cooling
closed symbols: heating



Acta Materialia 212 (2021) 116931



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Full length article

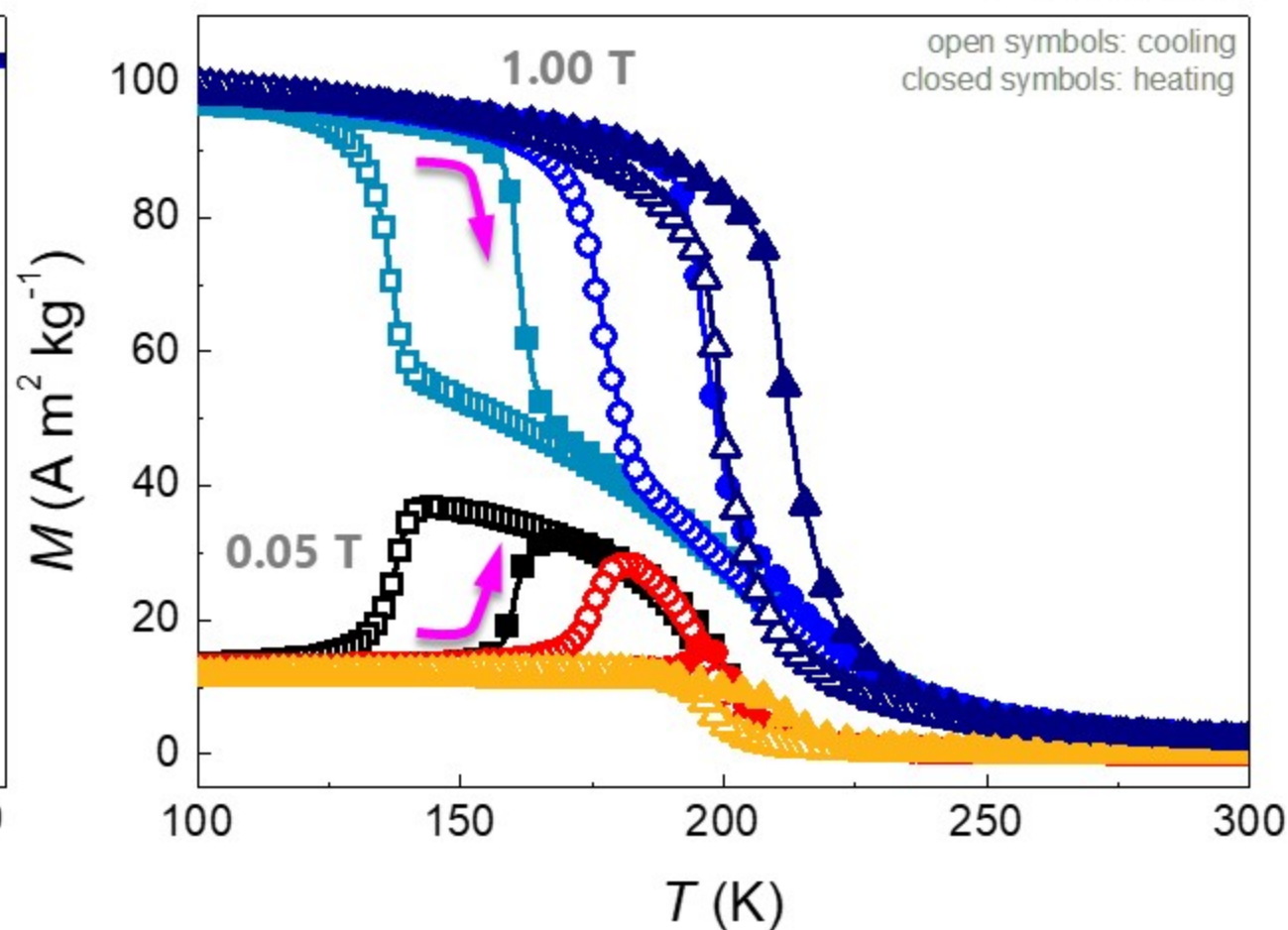
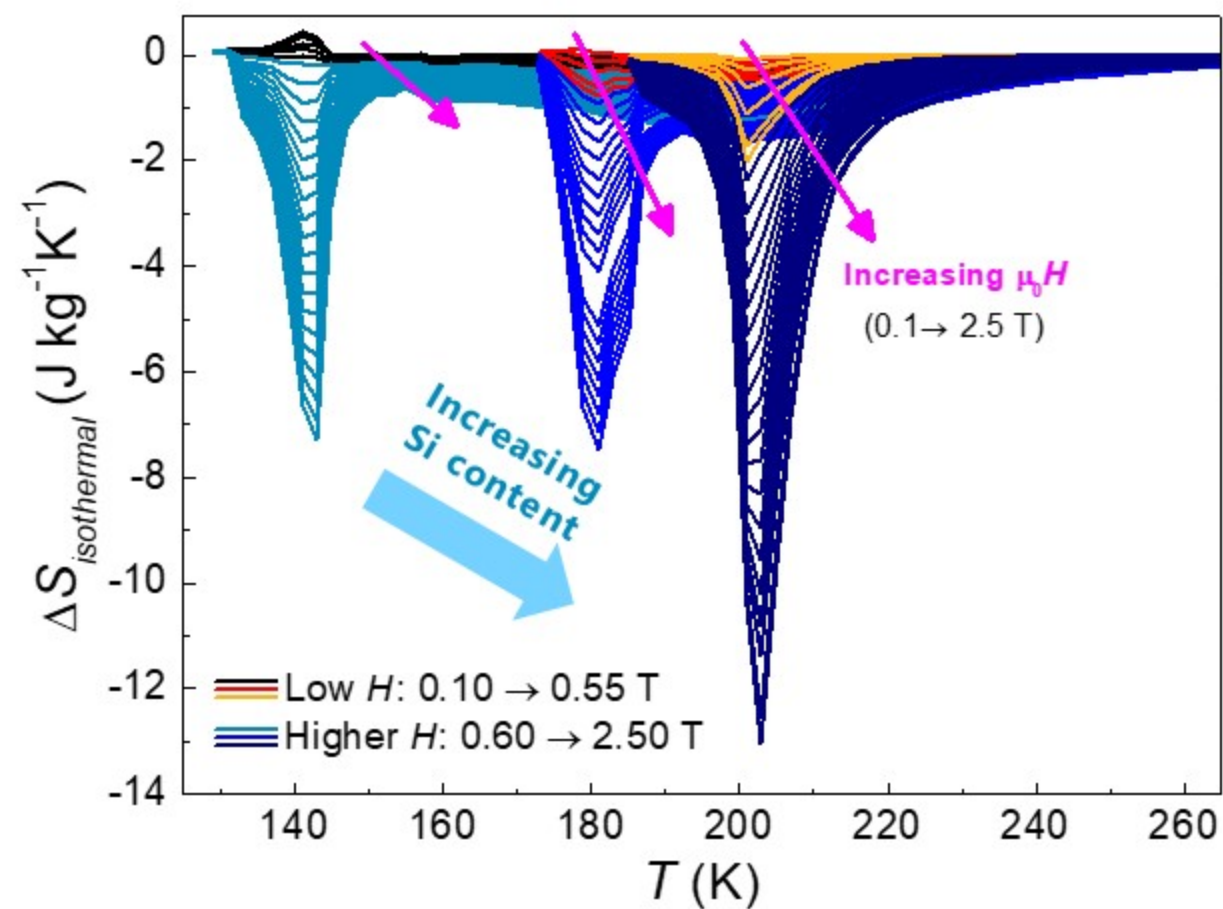
Increased magnetocaloric response of FeMnNiGeSi high-entropy alloys

Jia Yan Law*, Álvaro Díaz-García, Luis M. Moreno-Ramírez, Victorino Franco*

Departamento de Física de la Materia Condensada, ICMS-CSIC, Universidad de Sevilla, P.O. Box 1065, 41080-Sevilla, Spain

Fe-Mn-Ni-Ge-Si series

High and low fields



Fe-Mn-Ni-Ge-Si

their order of phase transitions?

to explore using their exponent n



Nat Commun 9 (2018) 2680

ARTICLE

DOI: 10.1038/s41467-018-05111-w

OPEN

A quantitative criterion for determining the order of magnetic phase transitions using the magnetocaloric effect

Jia Yan Law¹, Victorino Franco ¹, Luis Miguel Moreno-Ramírez¹, Alejandro Conde¹, Dmitriy Y. Karpenkov², Iliya Radulov², Konstantin P. Skokov² & Oliver Gutfleisch²

order of phase transition

can be determined by exponent n

$$\Delta S_{\text{isothermal}} \propto H^n$$

where n depends on temperature and field

$$n = \frac{d \ln |\Delta S_{\text{isothermal}}|}{d \ln H}$$

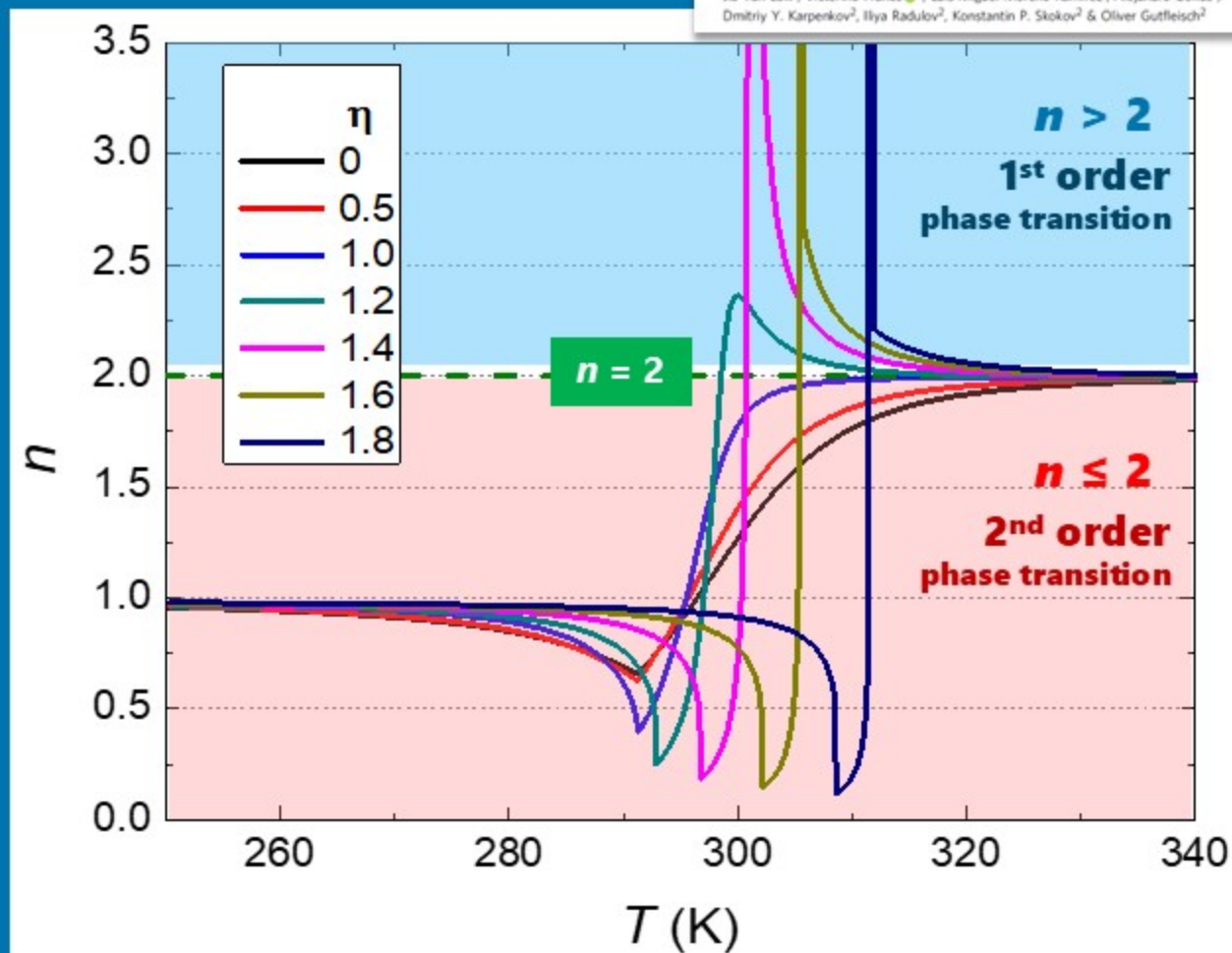
Bean and Rodbell model (order of phase transitions)

for $0 \leq \eta < 1$: **2nd order phase transition**

for $\eta = 1$: critical point

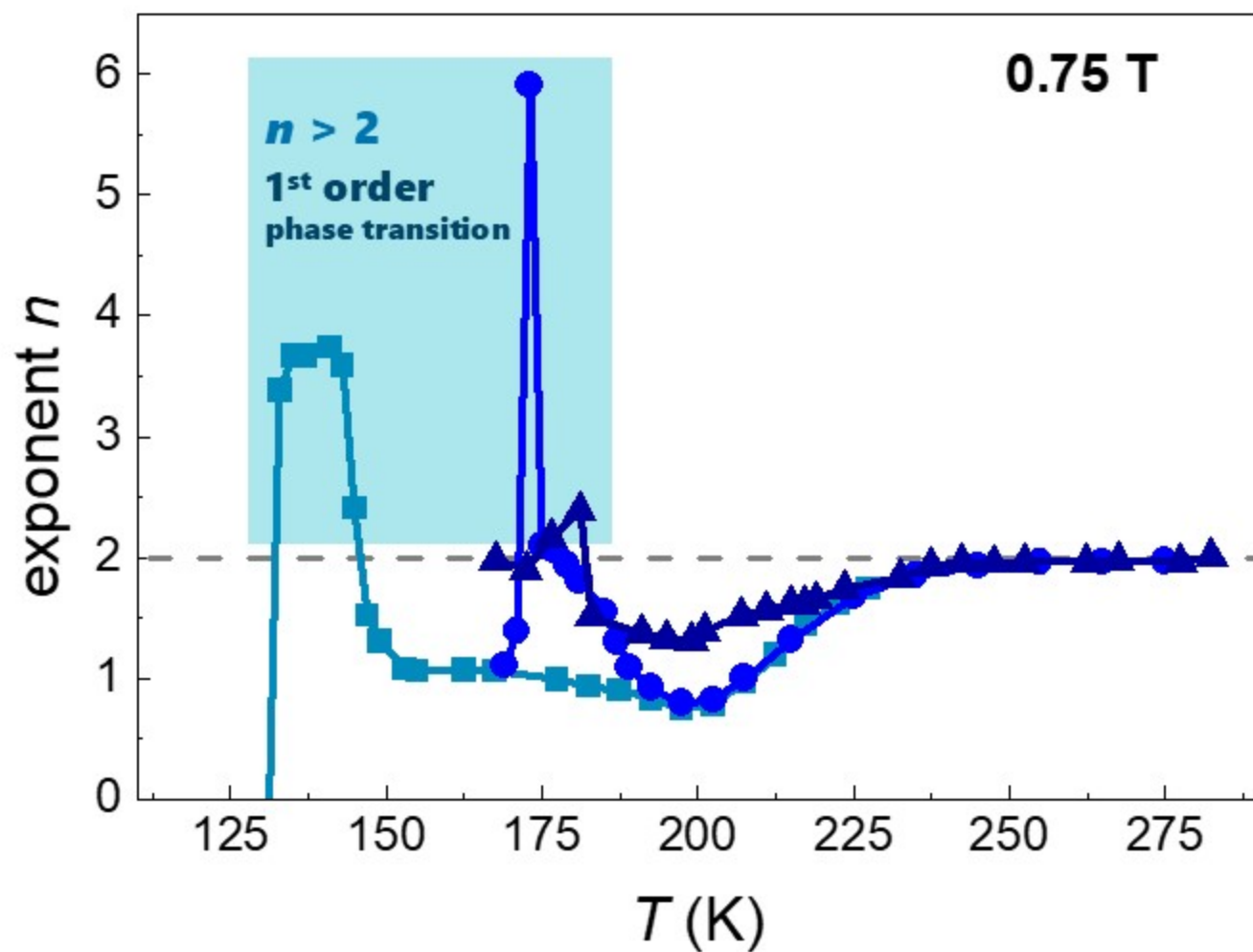
for $\eta > 1$: **1st order phase transition**

JY Law et al.,
Nature Communications 9 (2018) 2680



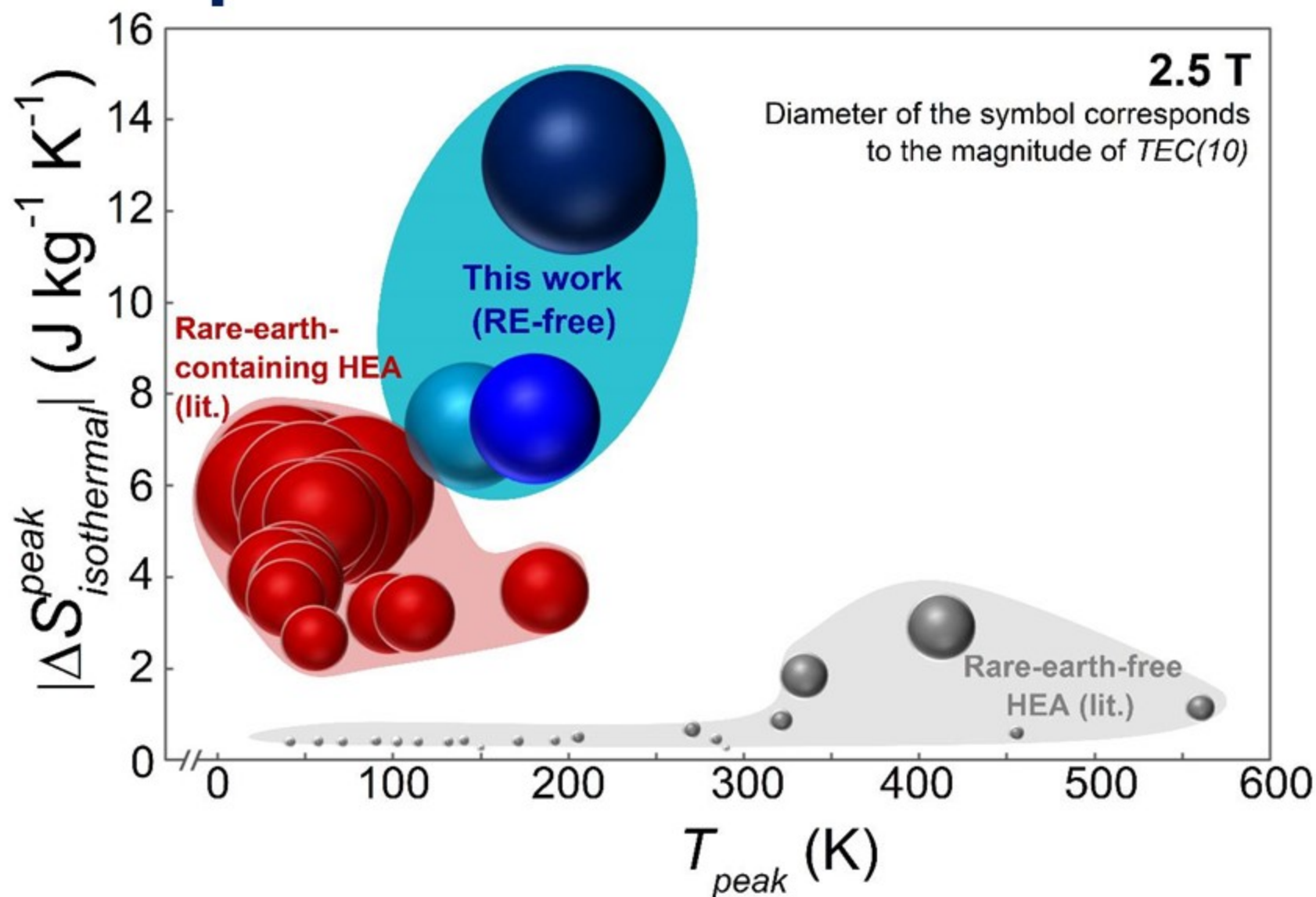
Fe-Mn-Ni-Ge-Si

order of phase transition



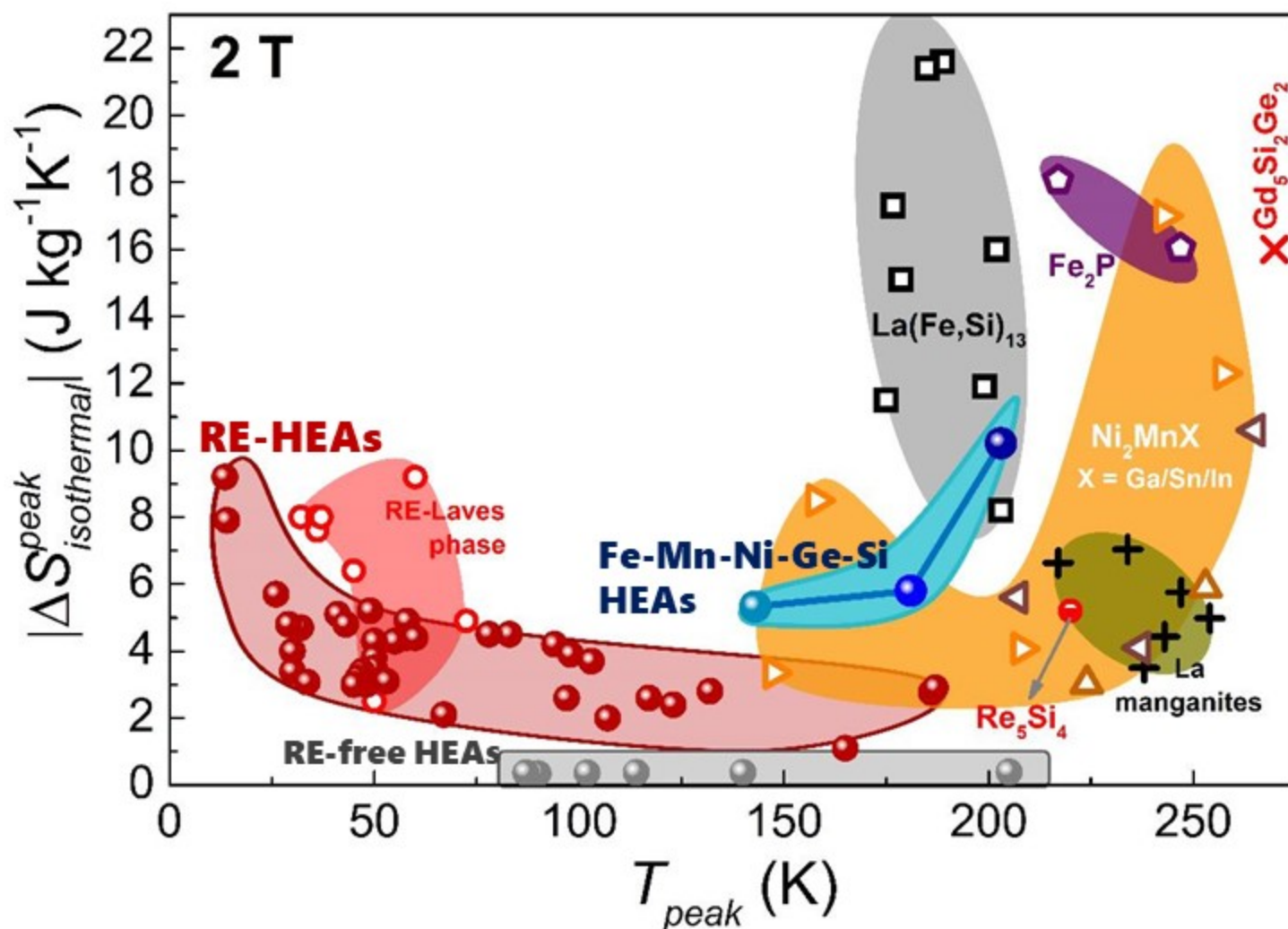
Fe-Mn-Ni-Ge-Si

How it compares with literature HEAs



Fe-Mn-Ni-Ge-Si

and what about with conventional MCE materials

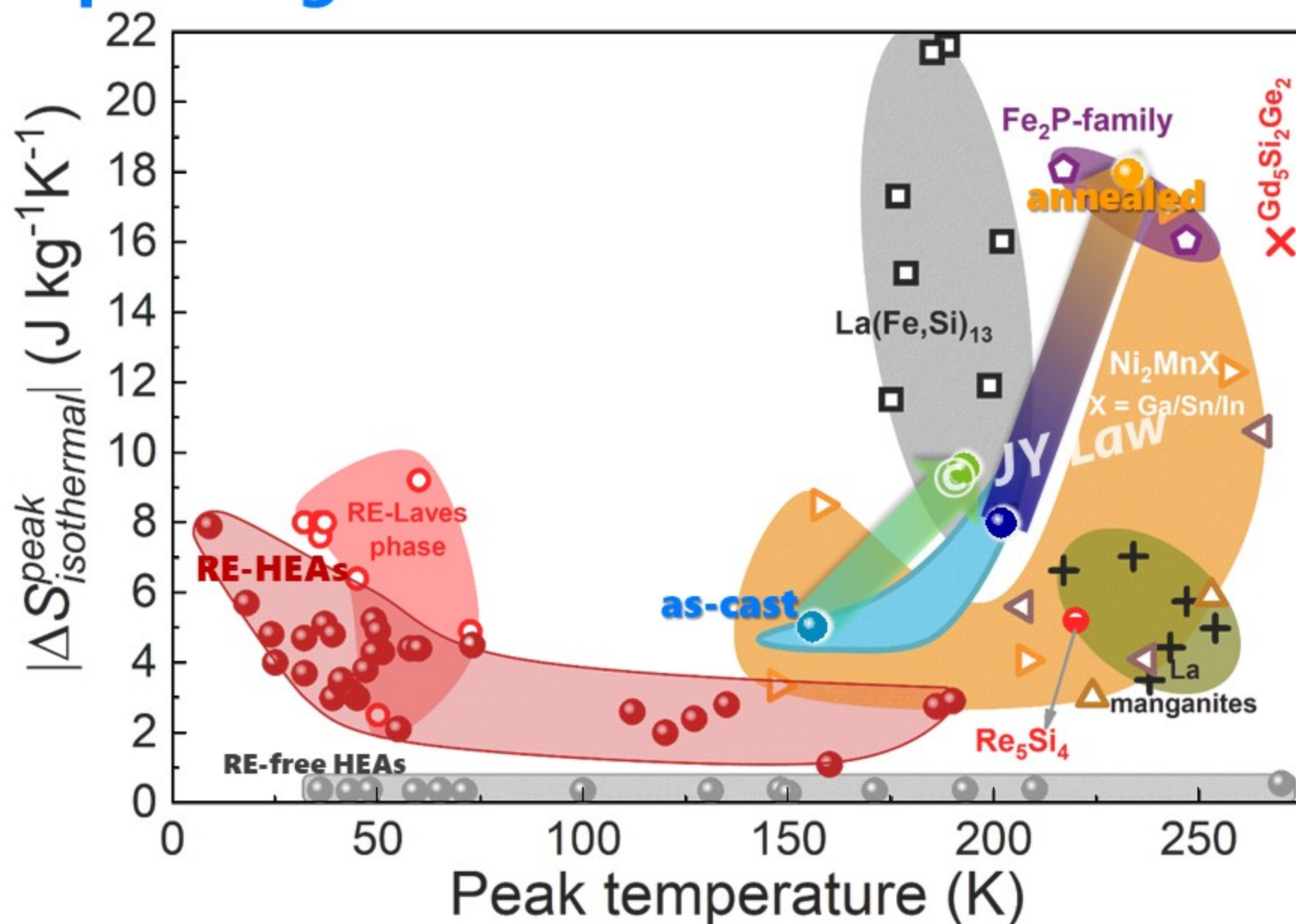


Fe-Mn-Ni-Ge-Si



**brought us
to further
works**

Fe-Mn-Ni-Ge-Si HEAs
and compare again





Find the HEA
Sweet Spot
when designing
compositions and tuning for
desired properties

Acknowledgment



Funded by
the European Union

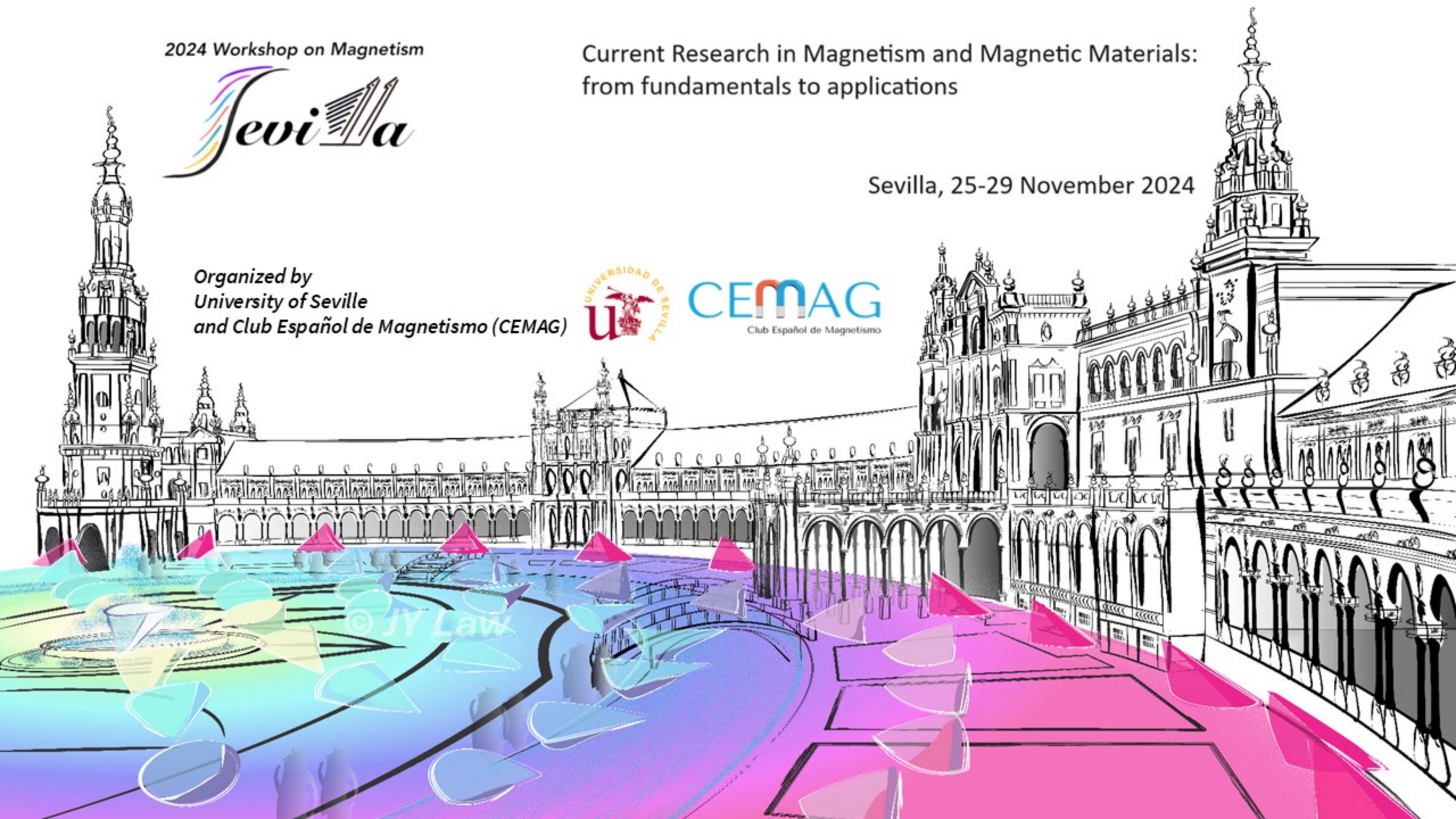
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Current Research in Magnetism and Magnetic Materials:
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University of Seville
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