DISENTANGLING UNIVERSAL AND NON-UNIVERSAL BEHAVIORS OF DOMAIN WALLS IN THIN MAGNETS

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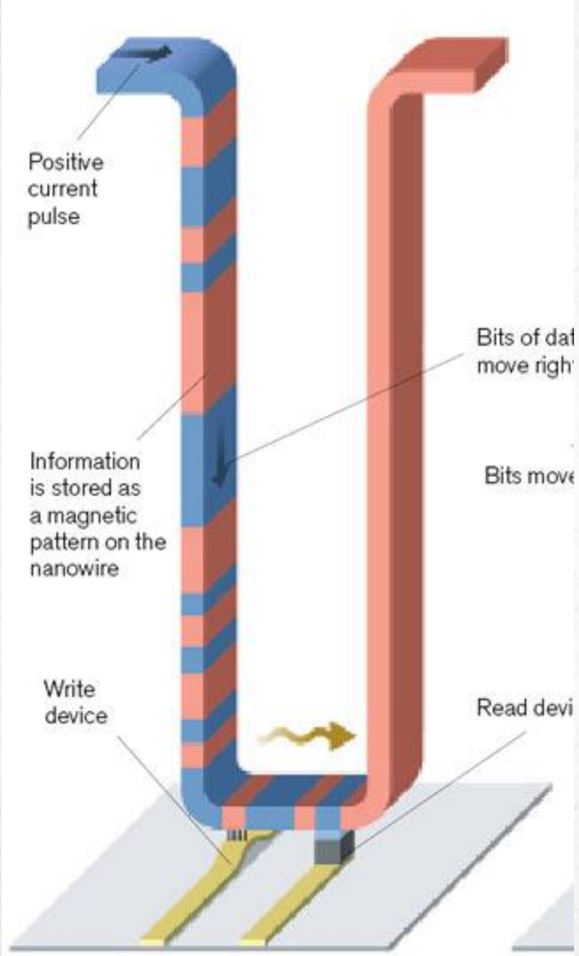
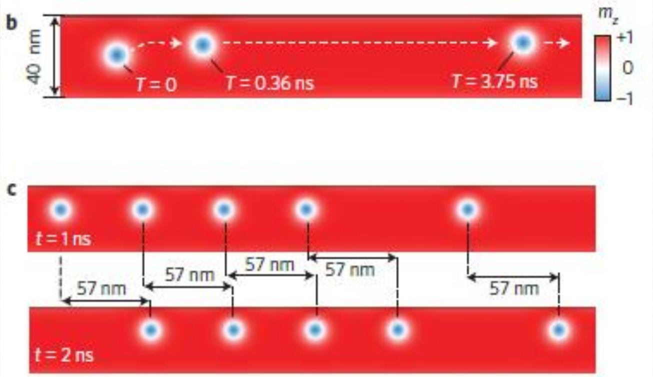
Context: motion of magnetic textures as domain walls & Skyrmions

Racetrack memory



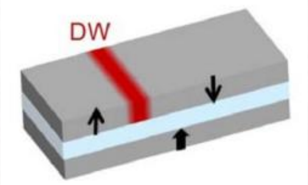
Parkin et al., Nat. Nano. ***10****, 195 (2015)*

Skirmions in nanotracks



Sampaio et al. Nature Nano. (2013)

Memory resistor (memristor)
Grolier *et al.*, Nat Electron. (2020)

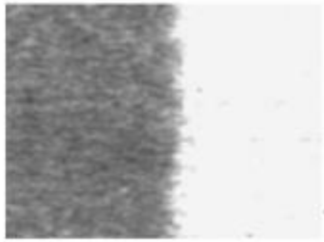


Potential application to magnetic data storage
- Requires high speed and controlled motion

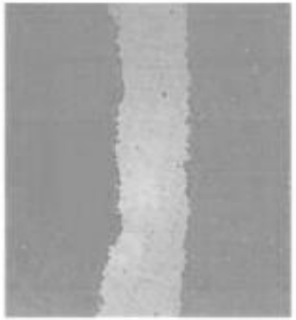
- However, spin textures are very sensitive to weak pinning defects ⇒
  Strong reduction of the mobility,
  Stochastic avalanche-like motion…

How to reduce and/or to control the pinning of magnetic texture?
- Engineering the pinning (annealing, irradiation…)
- Choice of weak pinning material…

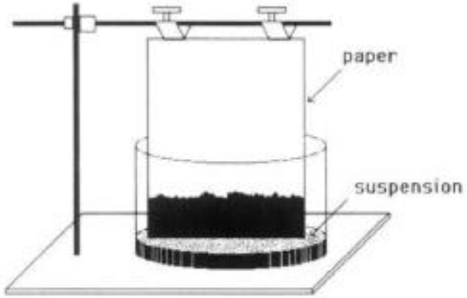
Context: motion of pinned interfaces



Domain walls
in ferroelectric films



Domain walls
in ferromagnetic films



Fluid impregnation

Bacteria colonies

Fluid wetting

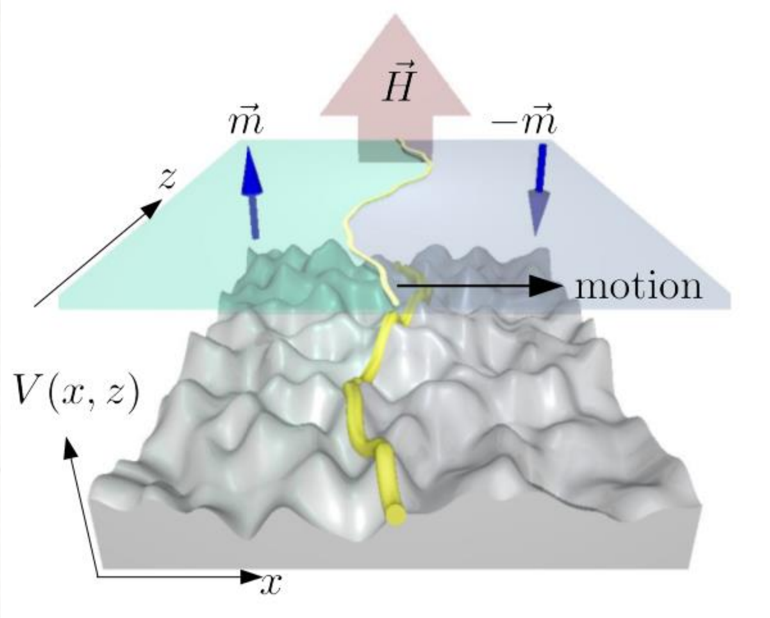
- Ubiquitous in nature
- Large variety of length scales and physical processes
- Present similar universal behaviors

How to identify universal behavior?
How to distinguish non-universal behaviors?

Context: disordered elastic systems

Generic framework

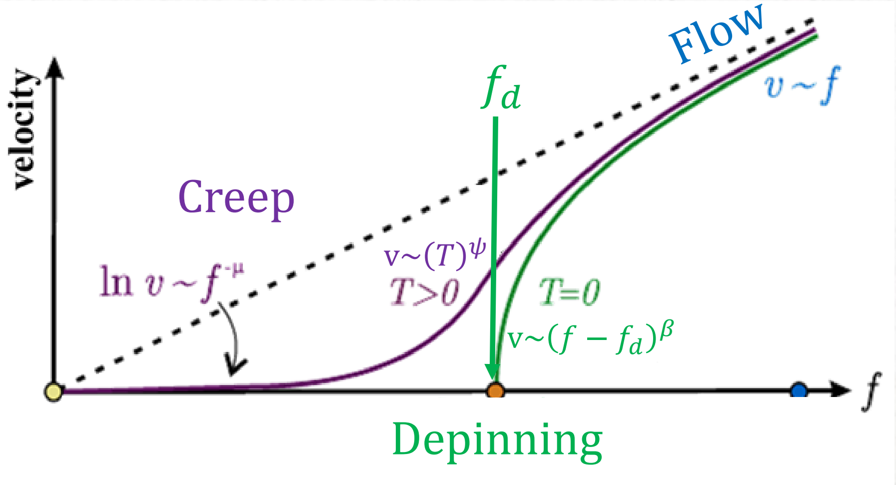
Huse et al., PRL 54, 2708 (1985); Chauve et al., PRB 62, 10 (2000); Le Doussal et al. PRB 66, 174201 (2002)



Minimal model (Edward-Wilkinson Eq.)
overdamped motion of elastic objects

$$\eta \frac{\partial u}{\partial t} = c\nabla^2 \mathbf{u} + F_{pin}(u) + \zeta_{rt} + f$$

Elasticity + pinning + noise + force



DW roughness: self affinity $u \sim L^{\zeta}$
Theoretical predictions for line moving in a 2d medium
Critical exponents: $\mu = \frac{1}{4}, \beta = 0.25, \psi = 0.15, \zeta = \frac{2}{3}$
Scaling relation: $\mu = \frac{2\zeta - 1}{2 - \zeta}$

To what extent minimal models can describe real physical systems?
How could we go beyond critical exponent analysis?

OUTLINE

1- INTRODUCTION TO DW STRUCTURE AND MOTION

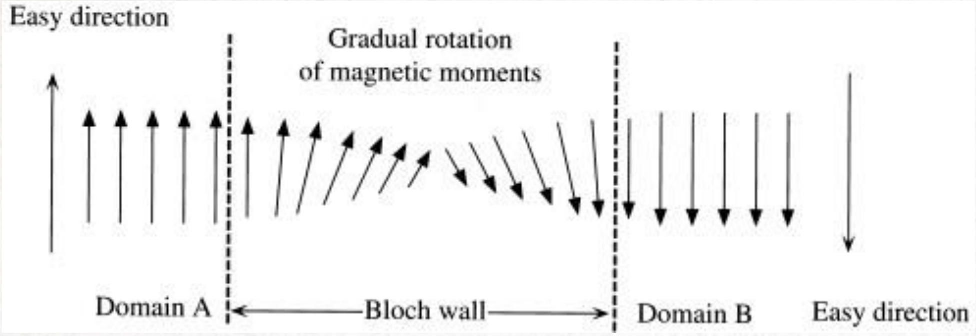
2- ANALYSIS OF CRITICAL BEHAVIORS

3- BEYOND ZERO DRIVE LIMIT AND POWER LAW SCALING
- Creep motion
- Depinning transition

4- MATERIAL DEPENDENT BEHAVIORS

What is a magnetic domain wall?

https://ars.els-cdn.com/content/image/3-s2.0-B9780815515937000072-f07-07-9780815515937.jpg



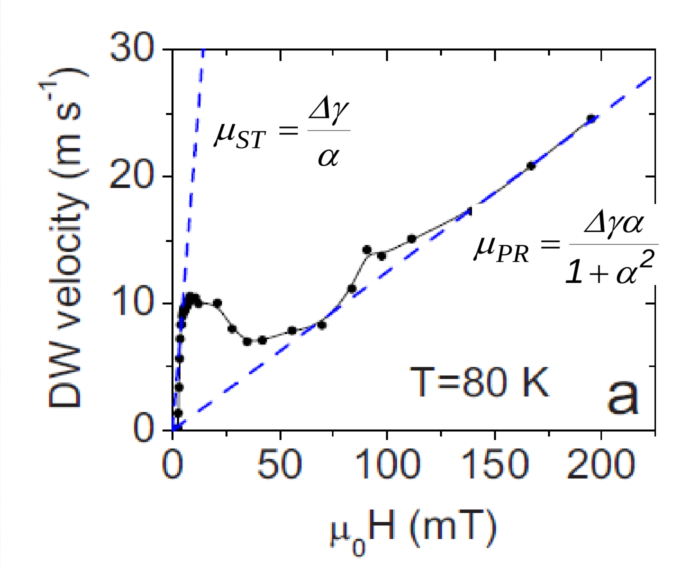
Perpendicular magnetic anisotropy
In domains, the magnetization M_s is fixed.

- Domain wall: region of magnetization reversal between domains
- Competition between
  - A: strength of interaction between magnetic moments
  - K: anisotropy => easy magnetization directions
- DW surface energy: $\sigma = 4\sqrt{AK}$ (Bloch wall)
- DW thickness: $\Delta \sim \sqrt{\frac{A}{K}} \approx 1 - 30nm$
- Origin of pinning: fluctuations of K, of M_s?

Malozemoff & Slonczewski (Academic Press, NY, 1979)

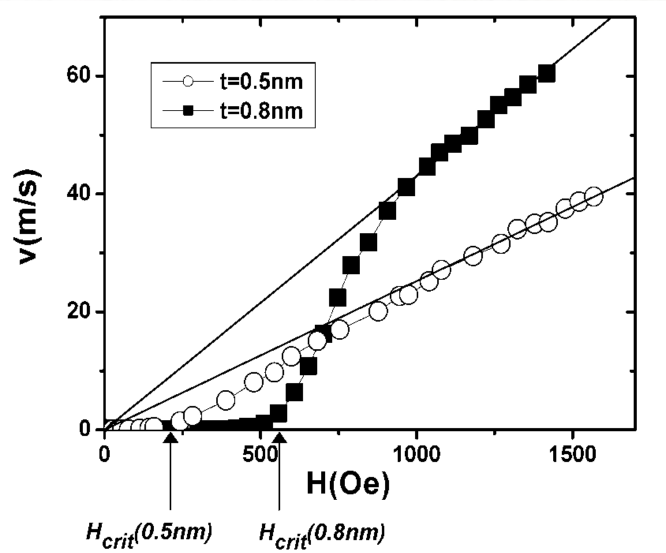
Flow regimes of domain walls

DW dynamics described by LLG Eq. : $\frac{d\vec{M}}{dt} = -\gamma\vec{M} \wedge \mu_0\vec{H}_{eff} + \alpha\frac{\vec{M}}{M} \wedge \frac{d\vec{M}}{dt}$ Schryer and Walker, J. Appl. Phys. **45**, 5406 (1974).



(Ga,Mn)As 50nm thick film

A. Dourlat *et al.*, PRB **78**, 161303R (2008)



Pt/Co/Pt ultrathin film

P. Metaxas et al., Phys. Rev. Lett. (2007)

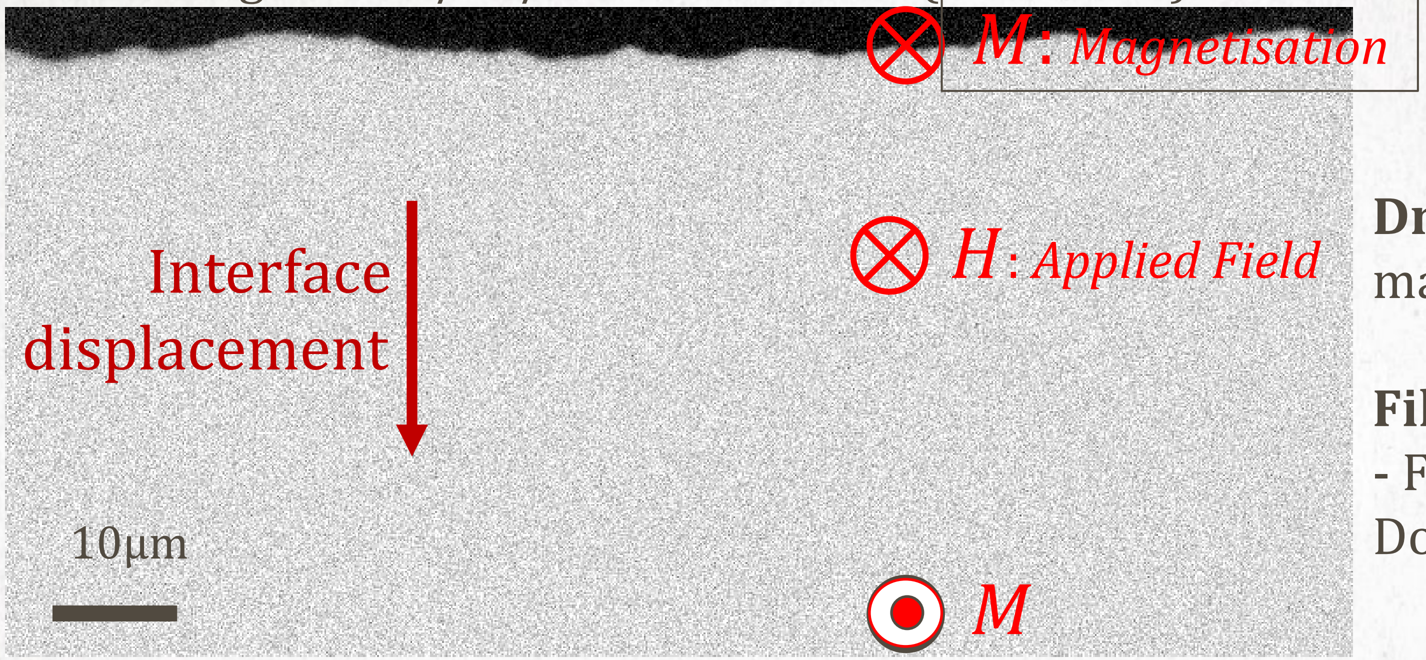
- Dynamics is controlled by dissipation
- Depends on the time evolution of DW magnetic texture (steady and precessional regimes)

For most of the materials, low drive regimes are hidden by DW pinning

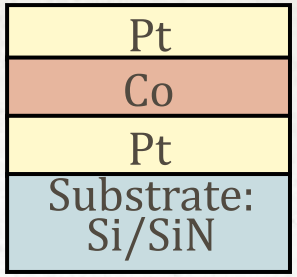
Motion of pinned domain walls

Ferromagnetic Pt/Co/Pt ultrathin film ($Co \approx 1nm$)

Magneto-optic Kerr Effect Microscopy



M. Bauer et al., Phys. Rev. Lett. (2005)

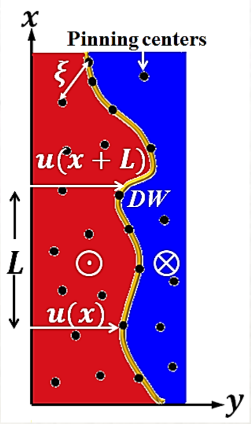


Driving force f is the magnetic field H. (=0.06 H_d)

Film thicknesses

- Films $\approx 1 - 80\ nm$

Domain wall $\Delta \approx 1 - 20\ nm$



Velocity: average displacement/duration

Interface roughness: correlation function of domain wall displacement
$w(L) = \langle (u(x+L) - u(x))^2 \rangle \propto L^{2\zeta}$

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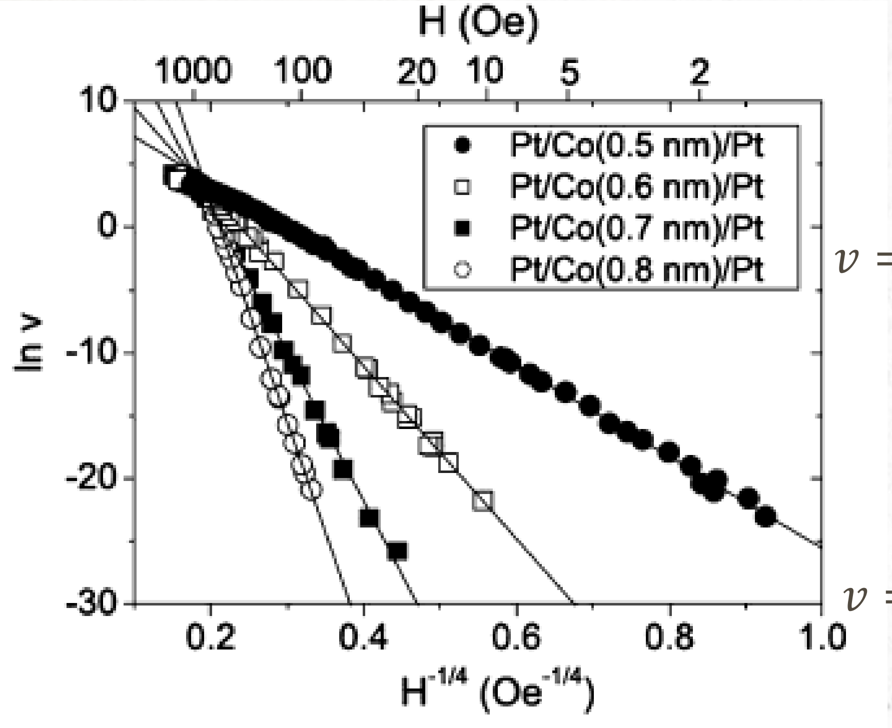
Connections of DW motion with creep theory

ultrathin Pt/Co/Pt film

Metaxas et al., Phys. Rev. Lett. **99**, *217208 (2007)*

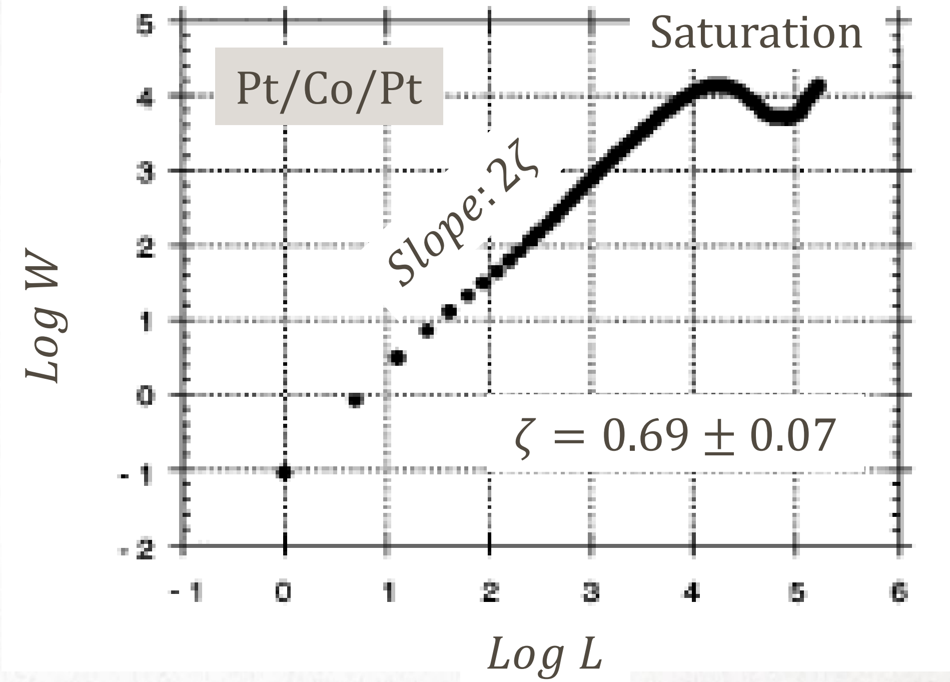


$v = 1m/s$

$v = 10^{-11}m/s$

Creep law: $lnv \sim H^{-\mu}$ with $\mu \approx 1/4$

Lemerle et al., Phys. Rev. Lett. **80**, *849 (1998)*



Roughness: $w(L) \propto \left(\frac{L}{L_c}\right)^{2\zeta}$ with $\zeta = 0.69 \pm 0.07$

Universal behavior: compatibility with the predictions $\mu \approx \frac{1}{4}, \zeta = \frac{2}{3}$ and the scaling $\mu = \frac{2\zeta - 1}{2 - \zeta}$

Domain wall ⇔ elastic line moving in 2d medium (no contribution of DW magnetic texture)

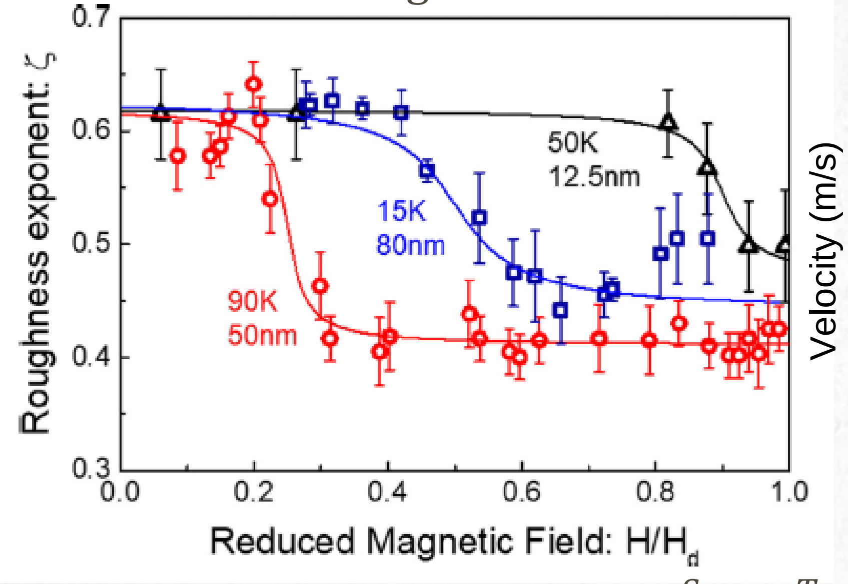
Power law analysis: dimensional cross over

Is there a thickness limit for the d=1 behavior of DW ?

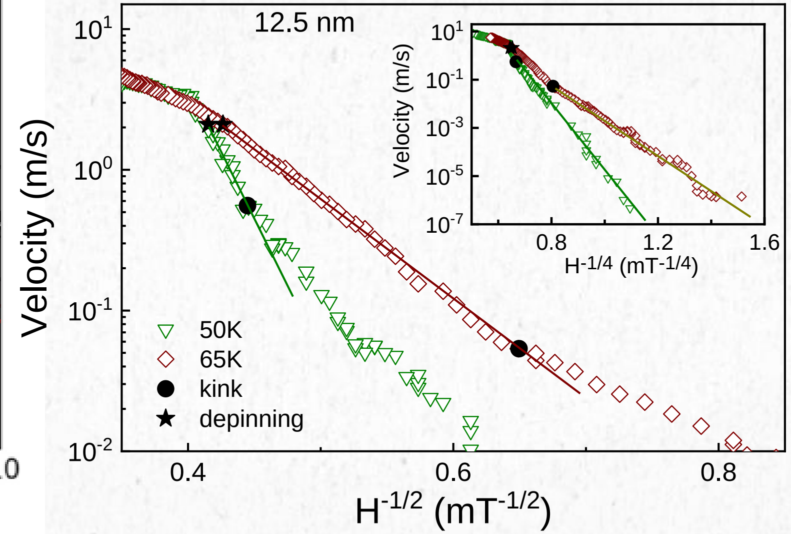
A. Kolton et al., Phys. Rev. B **79**, 184207 (2009)

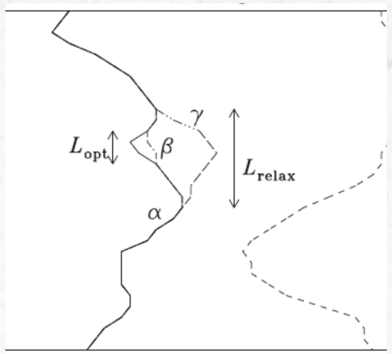
(Ga,Mn)As films with ≠ thicknesses: $t = 12.5\ nm, 50 nm, \&\ 80\ nm$

Roughness



Dynamics





Nuclei for DW jumps:

$L_{opt} \sim H^{-1/(2-\zeta_{eq})} \searrow$ for $H \nearrow$

Low drive $L_{opt} > t$: DW⇔ line

High drive $L_{opt} < t$:DW⇔ surface

Savero Torres et al., Phys. Rev. B. ***99****, 201201(R) (2019)*

- Double signature of a cross over: jump of the roughness and kink in the velocity curves

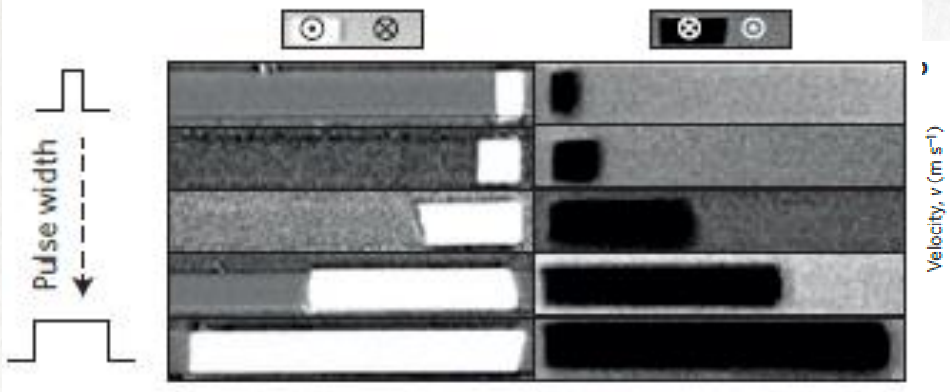
Low drive $\zeta_{1d} \approx \mathbf{0.62}$, $\mu \approx 1/4$: DW⇔ line in 2D medium

High drive $\zeta_{2d} \approx \mathbf{0.45}$, $\mu \approx 1/2$:DW⇔ surface in 3D medium

DW motion in tracks: contribution of edge pinning

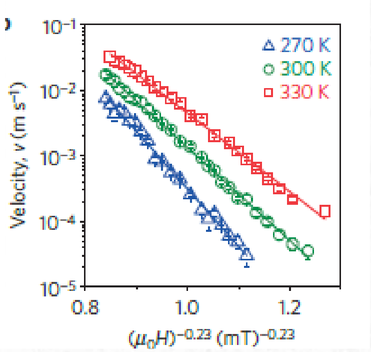
Current driven motion

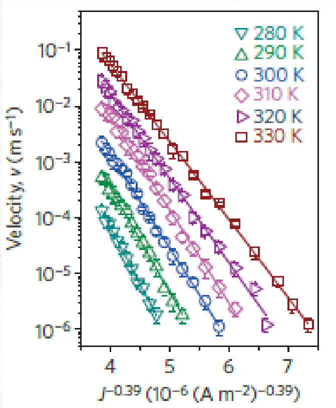
DuttaGupta et al. Nat. Phys. ***12****, 333 (2016)*

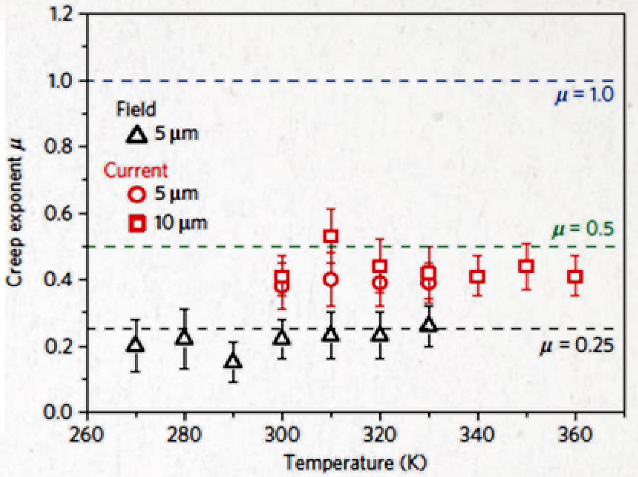


Ta/CoFeB/MgO 10μm wires

Signature of different universality classes for current and field driven DW motion? Yamanouchi *et al.*, Science 317, 1728 (2007).







Fit: $v \sim exp - \left(\frac{\Delta E}{k_B T}\right)$ with $\Delta E \sim f^{-\mu}$ *(only 2 -6 orders of magnitude, while 11 orders for Lemerle et al.)*

$\Rightarrow \mu_H = 0.23 \pm 0.07 \approx 1/4$ and $\mu_j = 0.39 \pm 0.06$

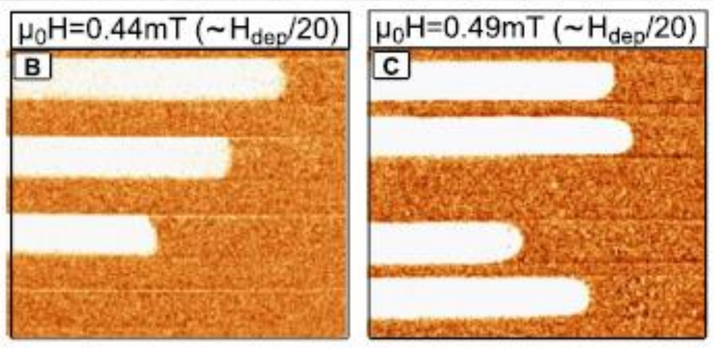
Different analysis (controversy)

- $\mu_H \neq \mu_j \Rightarrow$ different universality classes?
- For Pt/Co/Pt , $\mu_j = 1/4$ *Lee et al., Phys. Rev. Lett.* ***107****, 067201 (2011)* $\Rightarrow \mu_j$ depends on the material?
- Bending and tilting of domain wall: contribution of wire edge pinning?

DW motion in tracks: contribution of edge pinning

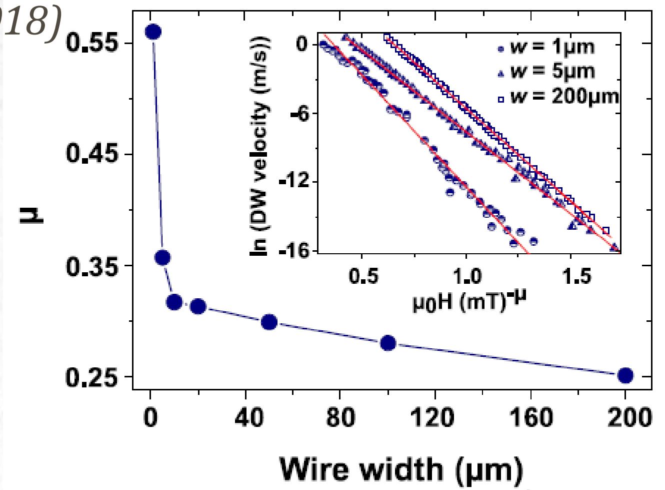
Field driven motion

Herrera Diez et al. Phys. Rev. B. ***98****, 054417 (2018)*



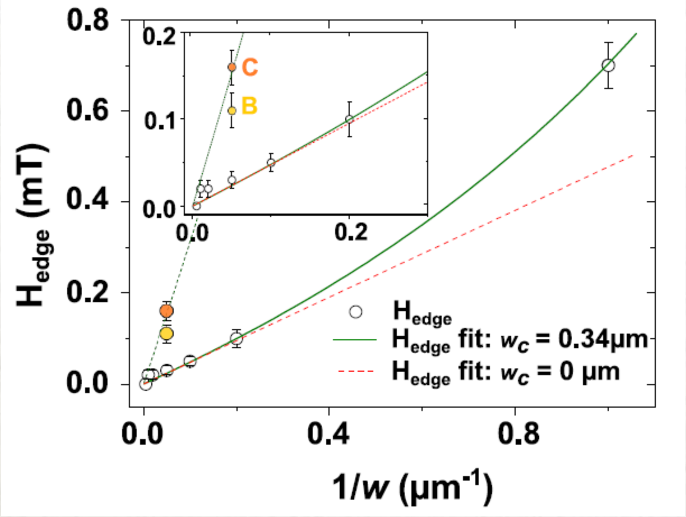
Ta/CoFeB/MgO 20μm wires

Contributions of wire edge pinning?



Fit: $v \sim exp - \left(\frac{\Delta E}{k_B T}\right)$ with $\Delta E \sim H^{-\mu}$

μ varies with the wire width ⇒ it is not a universal critical exponent.



Assumption: the bending of the DW reduces the drive: $H \rightarrow H - H_{edge}$

Fit with $\Delta E \sim (H - H_{edge})^{-\mu}$ assuming $\mu = 1/4$

Result: $H_{edge} \approx \frac{\sigma_e}{M_s w}$

Cf. Laplace law for a bubble: $\Delta P = \frac{2\sigma}{R}$

The bending of DW due to edge pinning reduces the driving field.
DW dynamics combines universal and non universal behaviors

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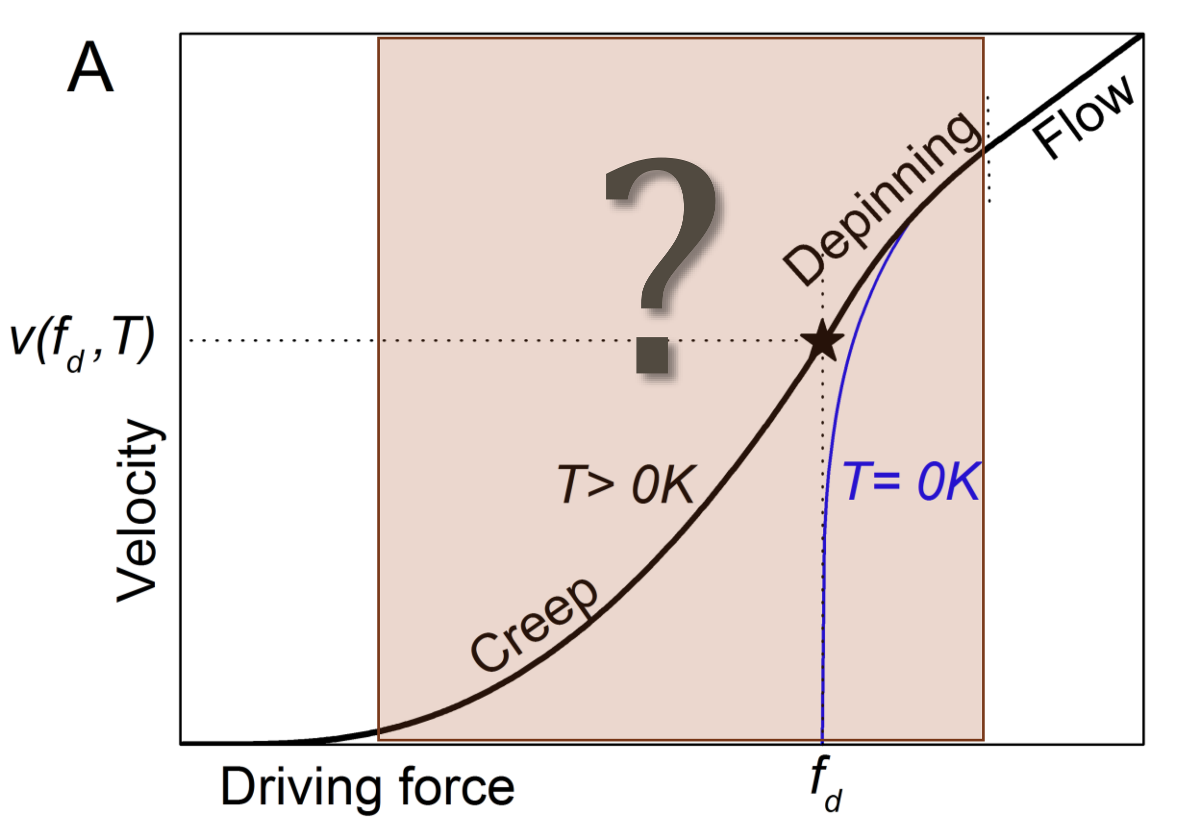
Open questions



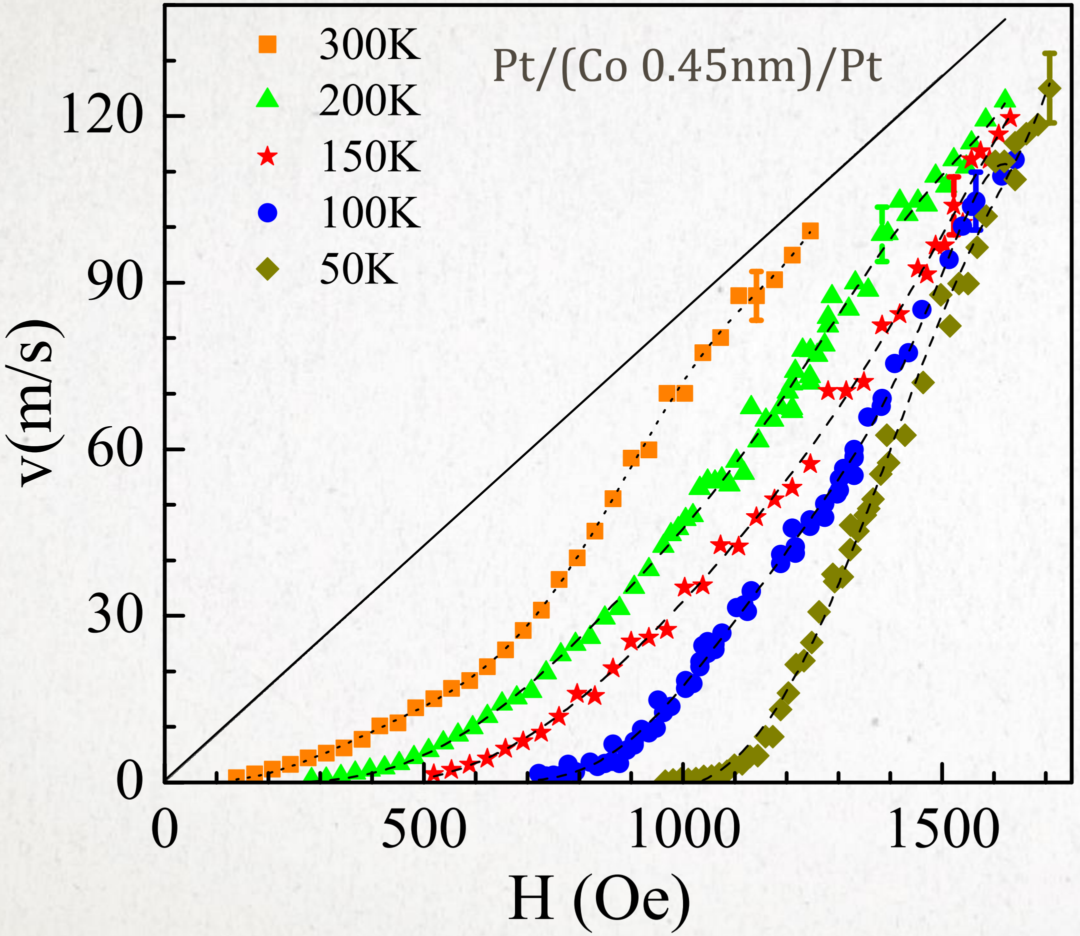
Extension of universal behaviors beyond the zero-drive limit?

Nature of domain wall dynamics: creep, TAFF... depinning, crossover to the flow?

Universality of the depinning transition?

Thermal studies of the creep motion

How to distinguish different dynamical regimes?



J. Gorchon *et al.*, PRL **113**, 027205 (2014)

Thermal studies:

- Variations of the thermal activation: $k_B T$
- Fixed frozen disorder
- but also, variations of magnetic properties:

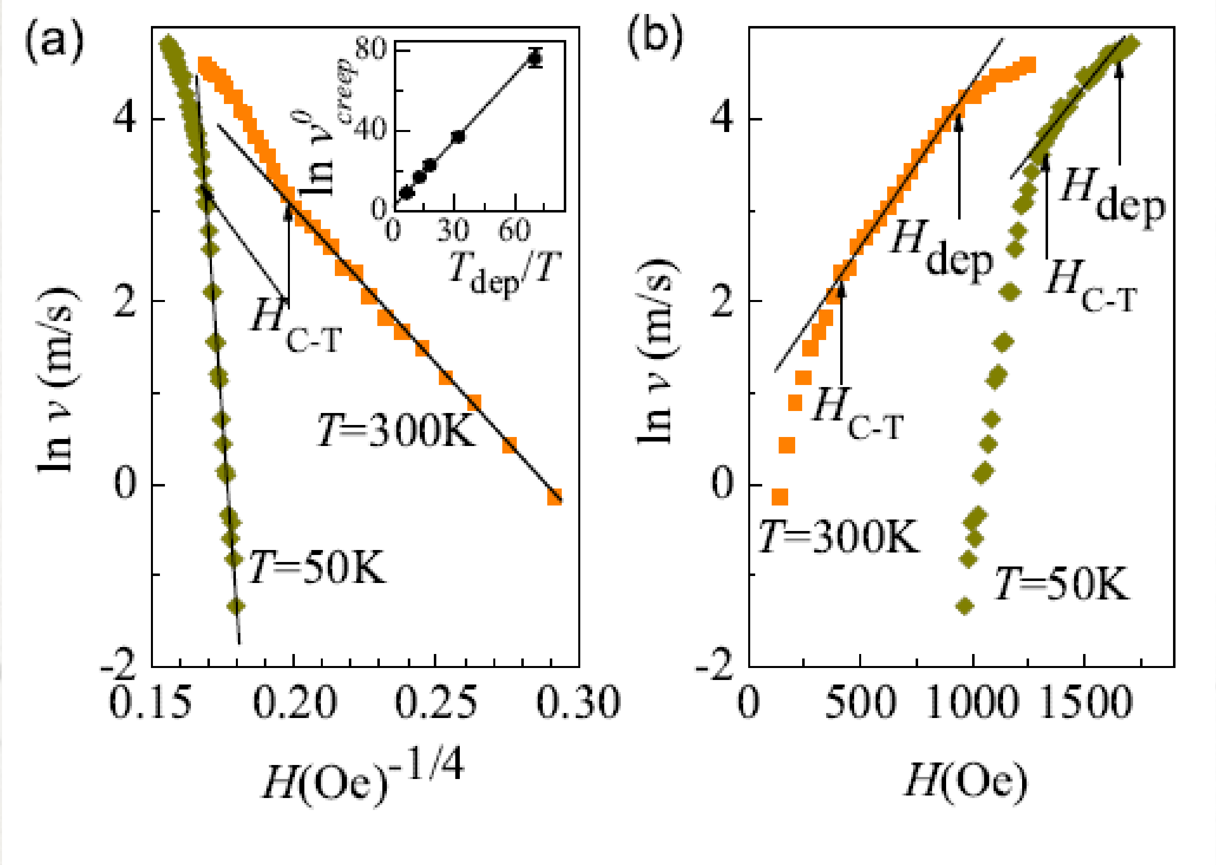
Magnetization M_s, DW energy σ, thickness Δ.

- $T \searrow \Rightarrow$ shifts of the curves towards the high field region.

- Boundaries between different regimes ?

Thermal studies of the creep motion

Shape of velocity curves compatible with available predictions ?



Creep : $H < H_{C-T}$

$$v_{creep}(H,T) = v^0_{creep}(T)\, e^{-\frac{T_d}{T}\left(\frac{H}{H_d}\right)^{-1/4}}$$

TAFF : $H_{C-T} < \mathrm{H} < H_d$

$$v_{TAFF}(H,T) = v^0_{TAFF}(T)\, e^{-\frac{T_d}{T}\left(1-\frac{H}{H_d}\right)}$$

Thermally Activated Flux Flow

P.W. Anderson and Y.B. Kim, Rev. Mod. Phys. (1964)

Other interpretation: Caballero et al. Phys. Rev. B **96**, 224422 (2017)

Depinning : $\mathrm{H} \geq H_d$

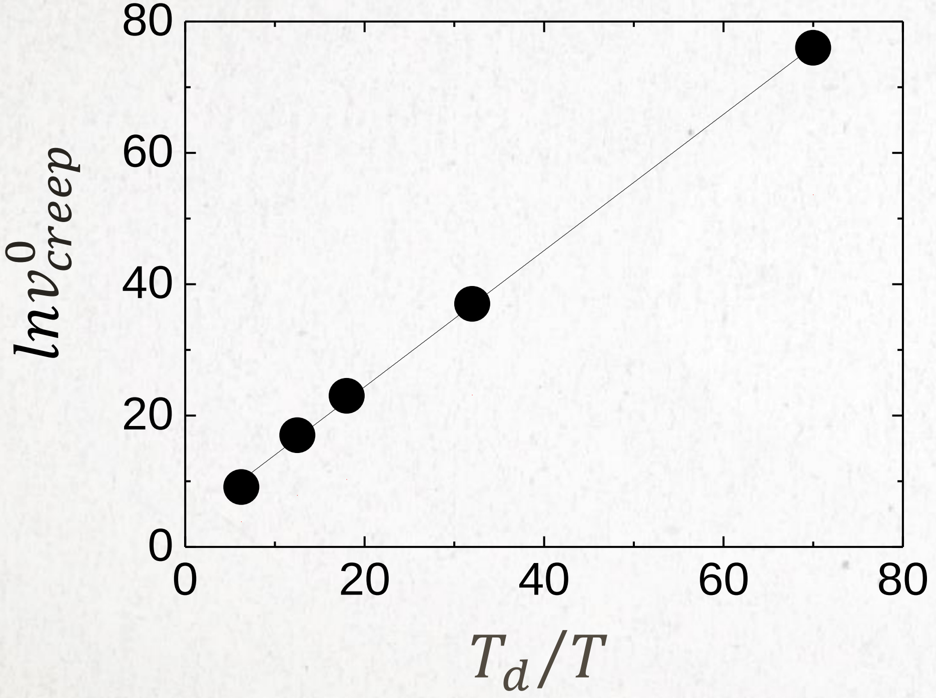
Flow : $\mathrm{H} \gg H_d$

Introduction of temperature dependent parameters: $T_d(T)$, $v^0_{creep}(T)$, $v^0_{TAFF}(T)$, $H_d(T)$, $H_{C-T}(T)$.

Thermal studies of the creep motion

Is the prefactor of the creep law temperature independent?

$$v_{creep}(H,T) = v^0_{creep}\ e^{-\frac{T_d}{T}\left(\frac{H_d}{H}\right)^{1/4}}$$



Expected: $v^0_{creep} \sim \xi/\tau$ weakly dependent on temperature

While, we observe: $v^0_{creep} \sim e^{\frac{T_d}{T}}$?

$\Rightarrow$ The scaling $\ln v \sim H^{-1/4}$ does not describe correctly $v_{creep}(H,T)$

Effective pinning barrier:

$$v_{creep}(H,T) \sim e^{-\frac{\Delta E}{k_B T}} \text{ with } \boldsymbol{\Delta E \approx k_B T_d \left(\left[\frac{H}{H_d}\right]^{-1/4} - 1\right)}$$

Boundaries of the creep regime:

$H \to 0 \quad \Rightarrow \Delta E \sim k_B T_d \left[\frac{H}{H_d}\right]^{-1/4}$ and $H \to H_d \Rightarrow \Delta E \to 0$

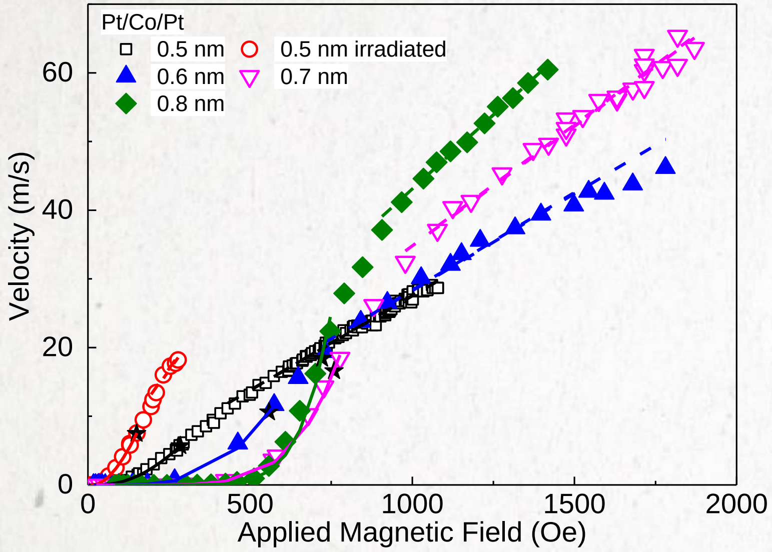
$\Rightarrow$ Universal variation of the reduced energy barrier $\frac{\Delta E}{kT_d}$ with the reduced drive $\frac{H}{H_d}$

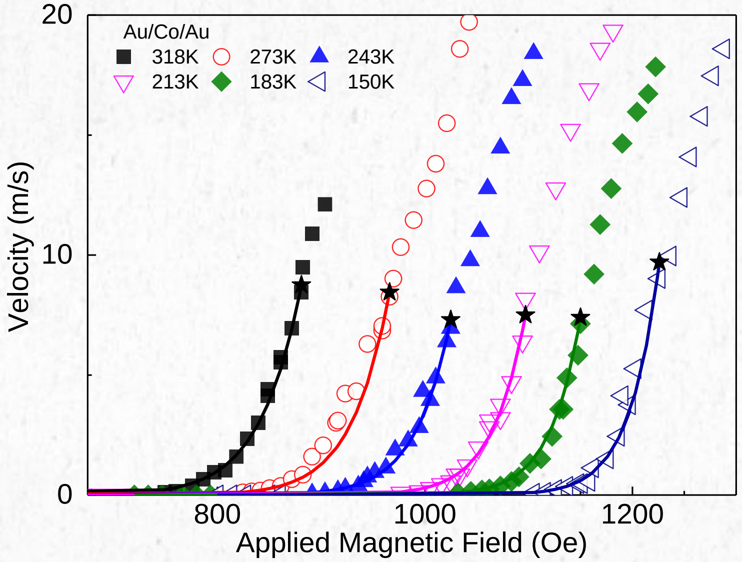
Evidencing universal creep behavior

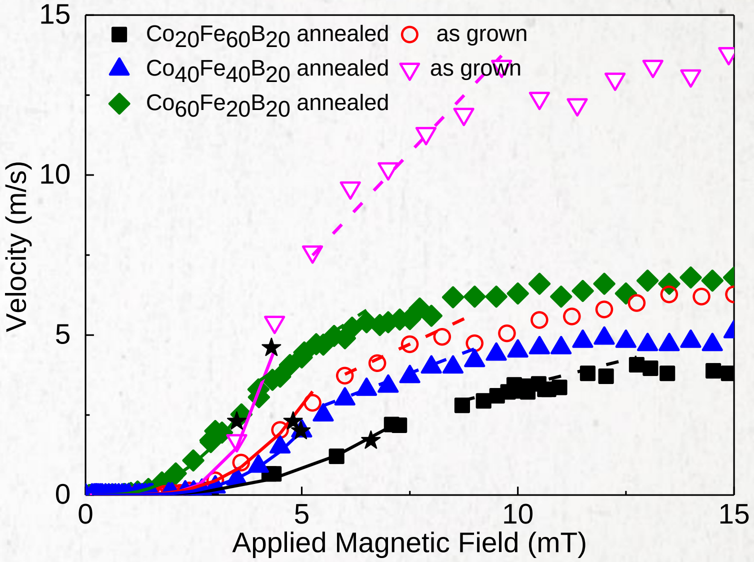
How to evidence a universal behavior of the creep motion?

Jeudy *et al.*, PRL **117**, 057201 (2016)

Different materials, large temperature range: $T = 10 - 315K$







Pt/Co/Pt : metallic ferromagnet
Different thickness: 0.5-0.8nm
Metaxas *et al.*, PRL99, 217208 (2007)

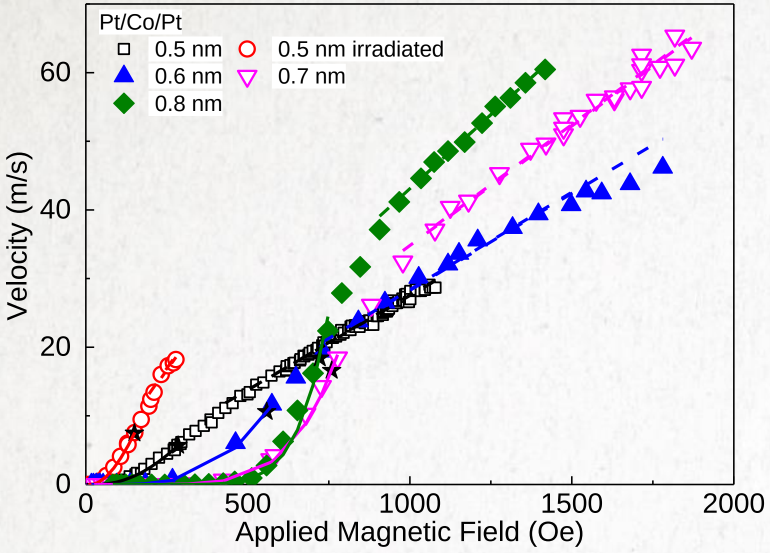
Au/Co/Au: metallic ferromagnet
Thickness: 1nm
Kirilyuk *et al.*, JMMM 171, 45 (1997)

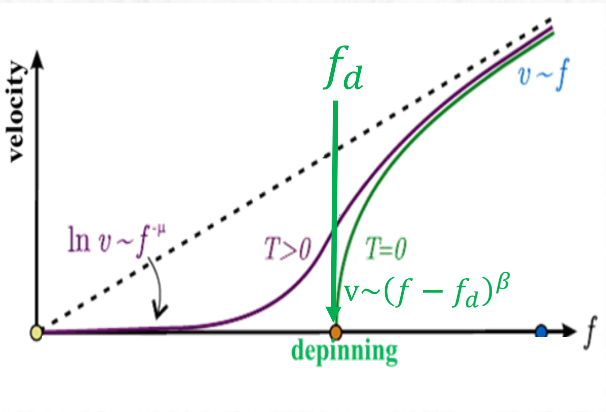
CoFeB: metallic ferromagnet
Thickness: 1nm
Burrowes *et al.*, APL 103, 182401 (2013)

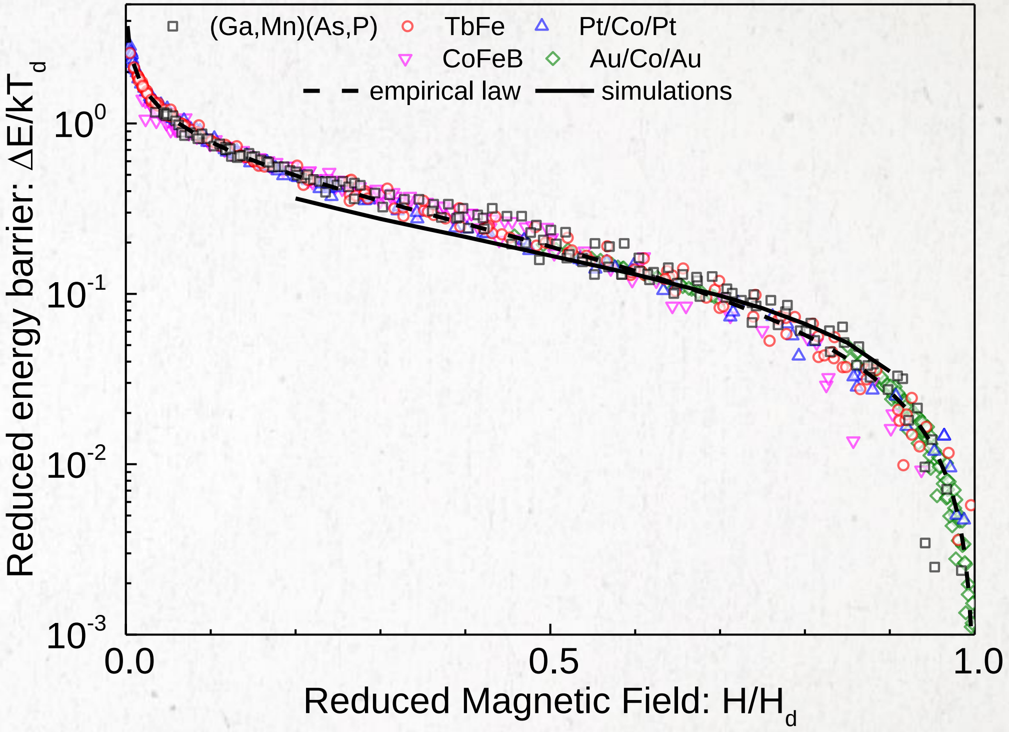
Universal behaviors: all the velocity curves have to collapse on a single master curve.

Evidencing universal creep behavior

Jeudy *et al.*, PRL **117**, 057201 (2016)







Methods:

Empirical law: $v = v(H_d, T)e^{-\frac{\Delta E}{k_B T}}$ with $\Delta E \approx k_B T_d \left(\left[\frac{H}{H_d}\right]^{-1/4} - 1\right)$

Upper boundary of the creep is the **inflection** point: $H = H_d, v = v(H_d)$

Fit of the creep law $\Rightarrow T_d$

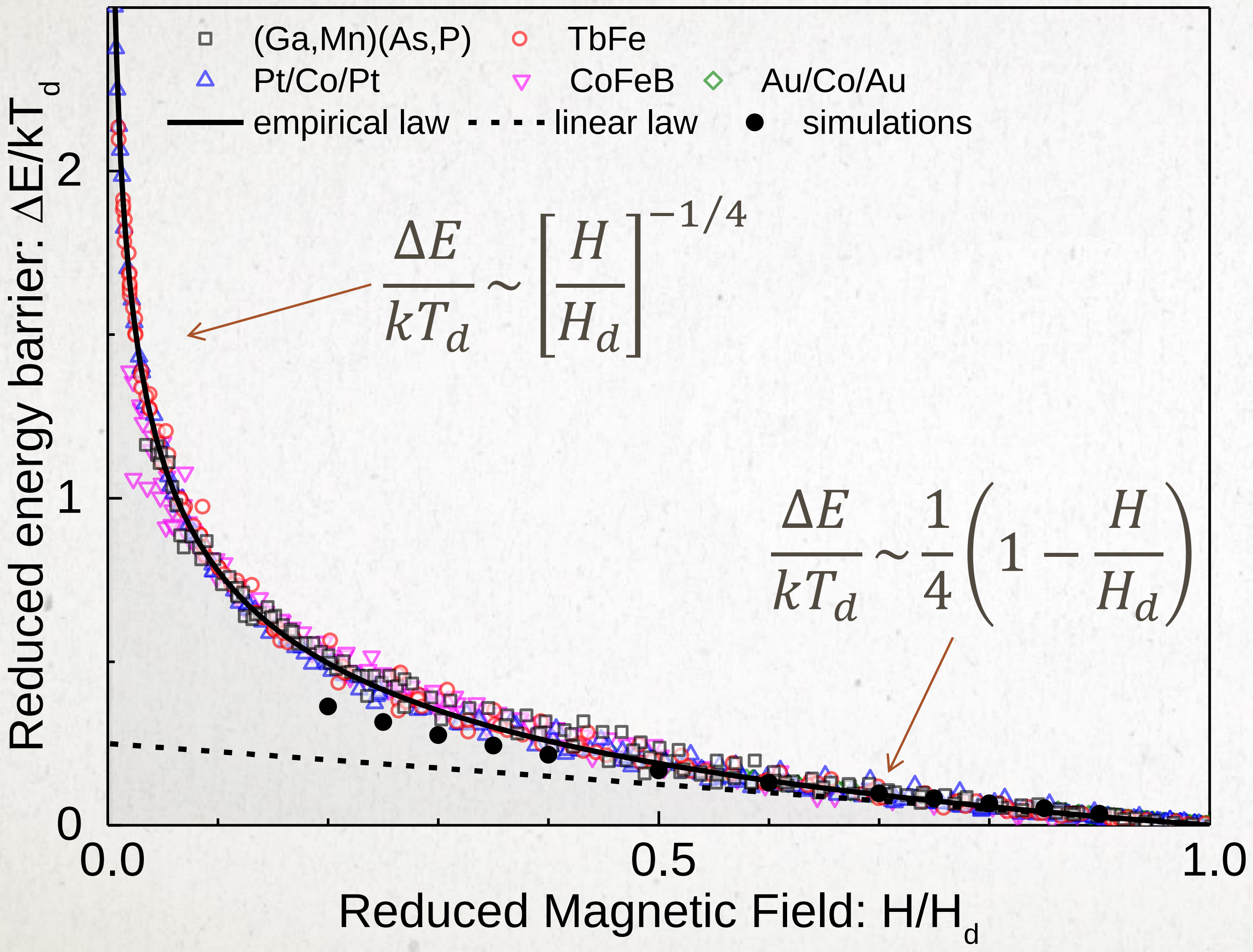
Then $\Delta E = -k_B \mathrm{T} \ln \frac{v(H,T)}{v(H_d,T)} \Rightarrow \frac{\Delta E}{k_B T_d}$ versus $\frac{H}{H_d}$

Collapse of 25 curves on a single master curve

More than 3 orders of magnitude in $\frac{\Delta E}{kT_d}$

Evidencing universal creep behavior: the universal barrier function

Jeudy *et al.*, PRL **117**, 057201 (2016)



- The exponent ($\mu = 1/4$) describes the whole creep motion up to the depinning transition.

- Close to $H = 0$,

Agreement with the prediction $\Delta E \sim H^{-1/4}$

- Close to H_d,

The TAFF regime is part of the creep motion.

Agreement numerical simulations

Kolton et al., PRB **79**, 184207 (2009)

The creep motion can be described by

- a universal barrier function and
- 3 non-universal parameters :

H_d, $v(H_d)$, and T_d

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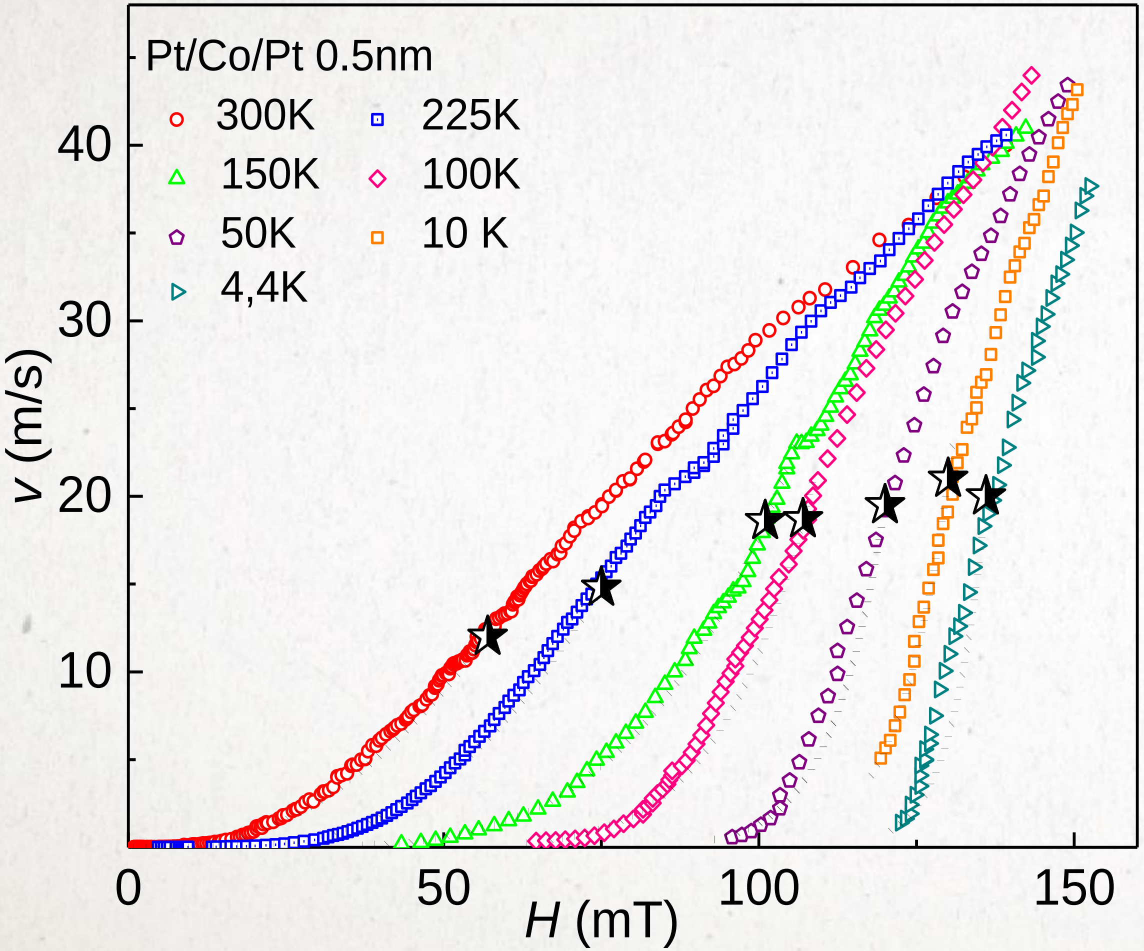
Depinning transition: thermal studies



Does the depinning transition present universal behaviors?
Contribution of DW magnetic texture?
Diaz Pardo *et al.*, PRB **95**, 184434 (2017)

Le Doussal *et al.*, PRB 66, 174201 (2002)
Bustingorry *et al.*, EPL 81, 26005 (2008)
Bustingorry *et al.*, PRE 85, 021144 (2012)
Bustingorry *et al.*, PRB 85, 214416 (2012)

Predictions: $f \geq f_d$
for $f = f_d, v \sim T^{\psi}$ with $\psi = 0.15$
for $T = 0K, v \sim (f - f_d)^{\beta}$ $with\, \beta = 0.25$

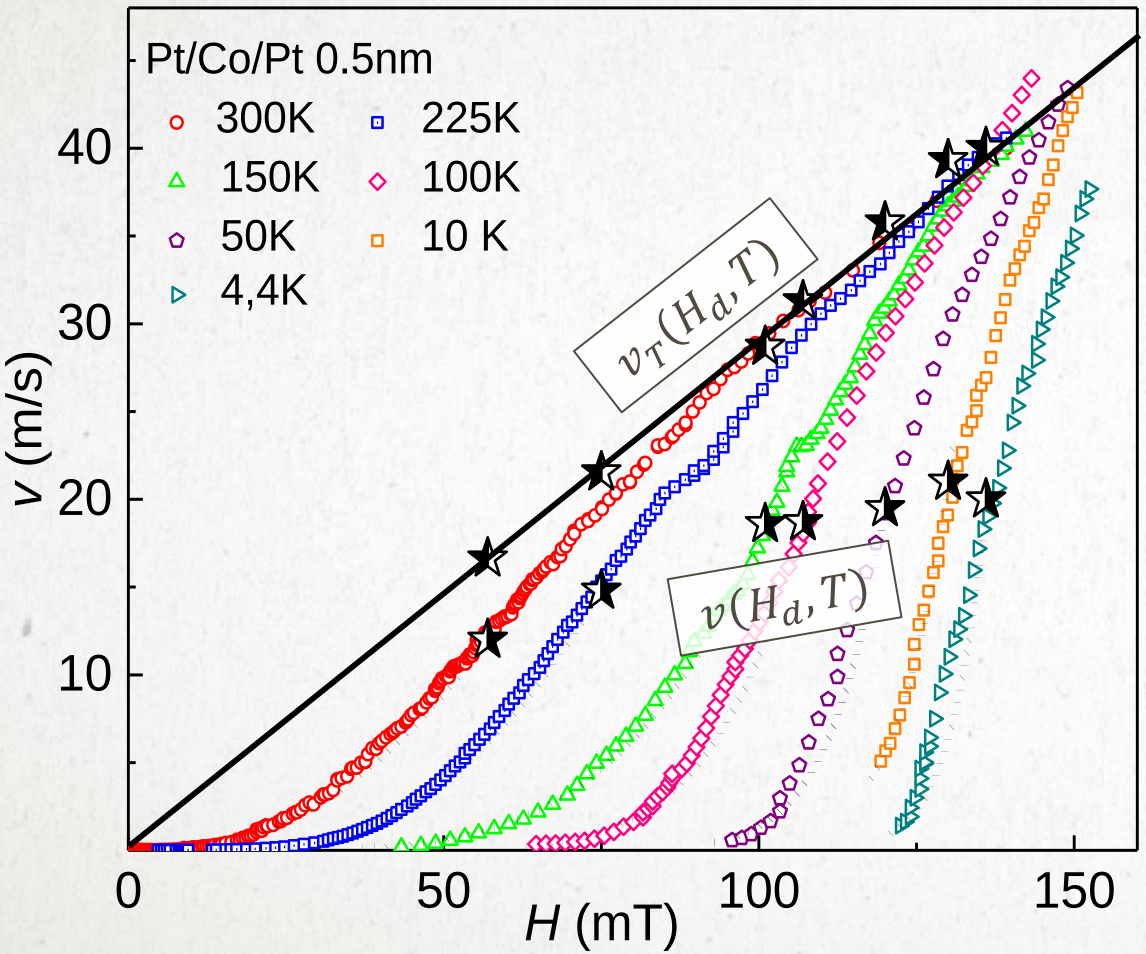
Introduction of non-universal parameters

for $H = H_d, v(H_d, T) = v_T(H_d, T) \cdot \left(\frac{T}{T_d}\right)^{\psi}$

for $T = 0K,\ v(H, T) = v_H(H_d, T) \left(\frac{H-H_d}{H_d}\right)^{\beta}$

Compatibility with experimental results ?
Meaning of v_T and v_H?

Thermal studies of the depinning transition



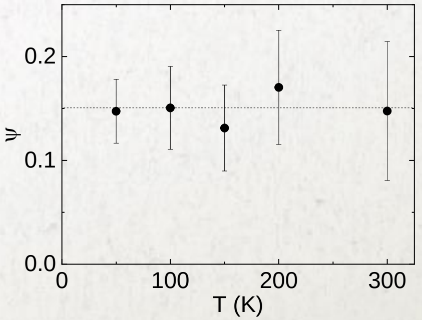
At the depinning transition $H = H_d$:

$v_T(H_d,T) = v(H_d,T) \cdot \left(\frac{T_d}{T}\right)^{\psi}$, with ψ=0.15

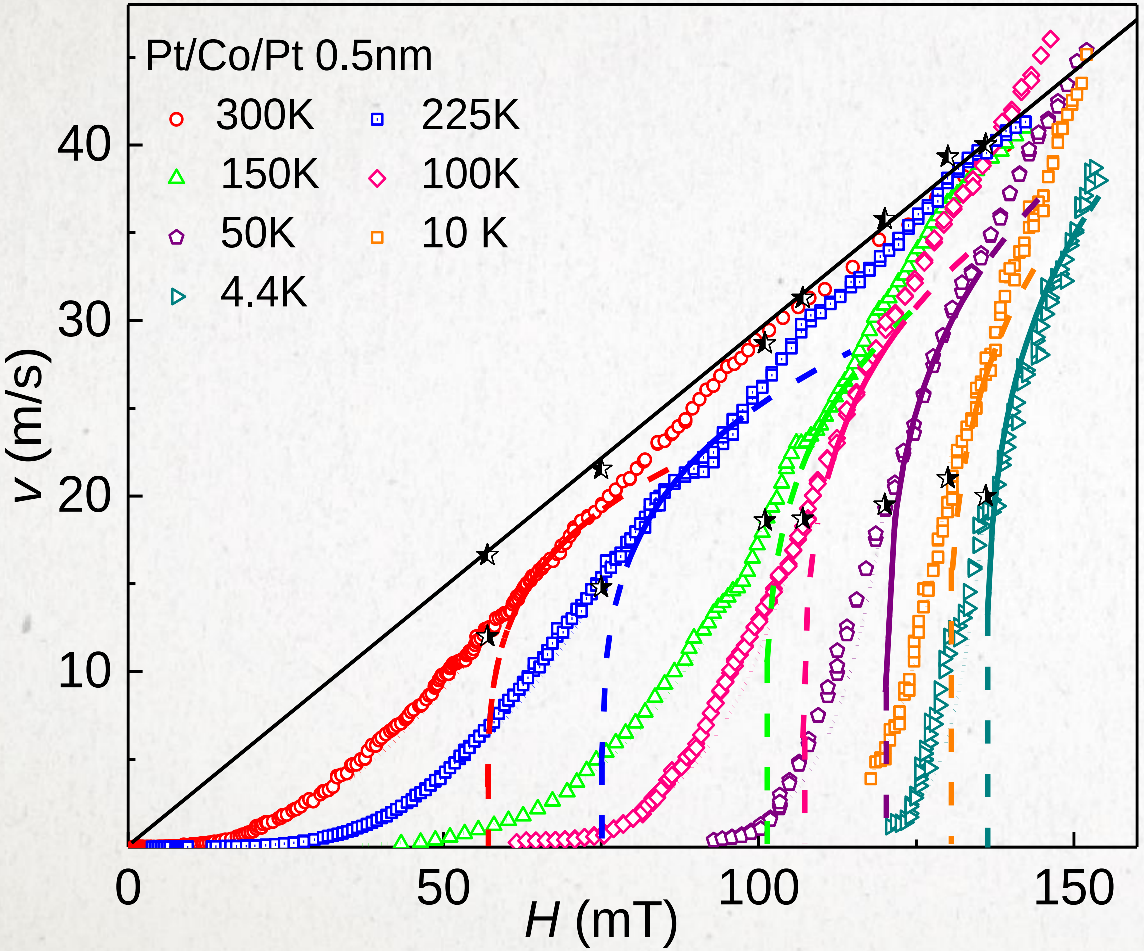
Meaning of the depinning velocity v_T?

v_T coincides with the extrapolation of the flow regime
$\Rightarrow v_T$ is the flow velocity DW would have without pinning.

ψ can be deduced from experiments:



Thermal studies of the depinning transition



Above the depinning transition: $H > H_d$

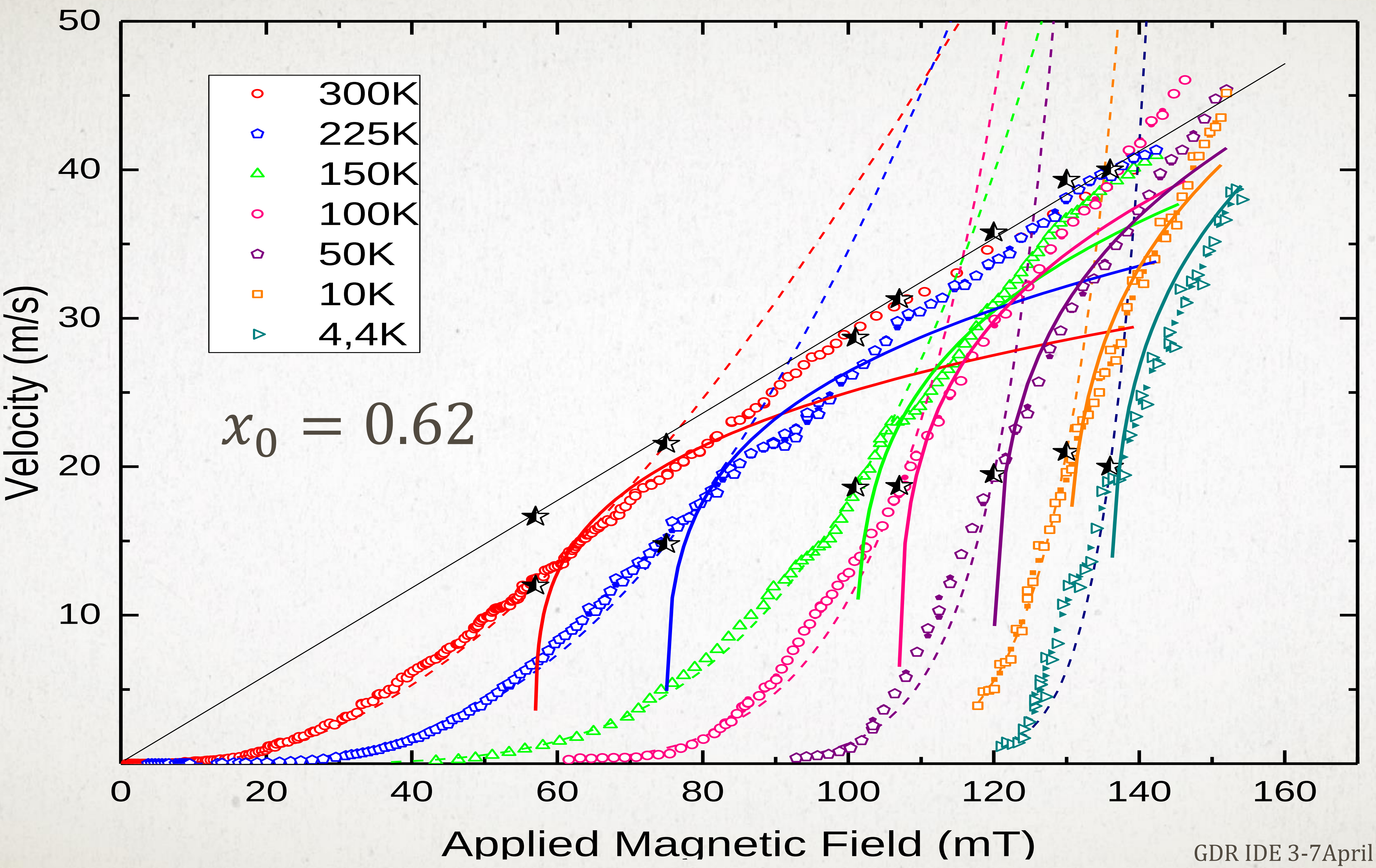
$v(H, T \rightarrow 0K) = v_H\ (H_d, T)\left(\frac{H-H_d}{H_d}\right)^{\beta}$, with β=0.25

$\Rightarrow$ agreement with a segment of curves

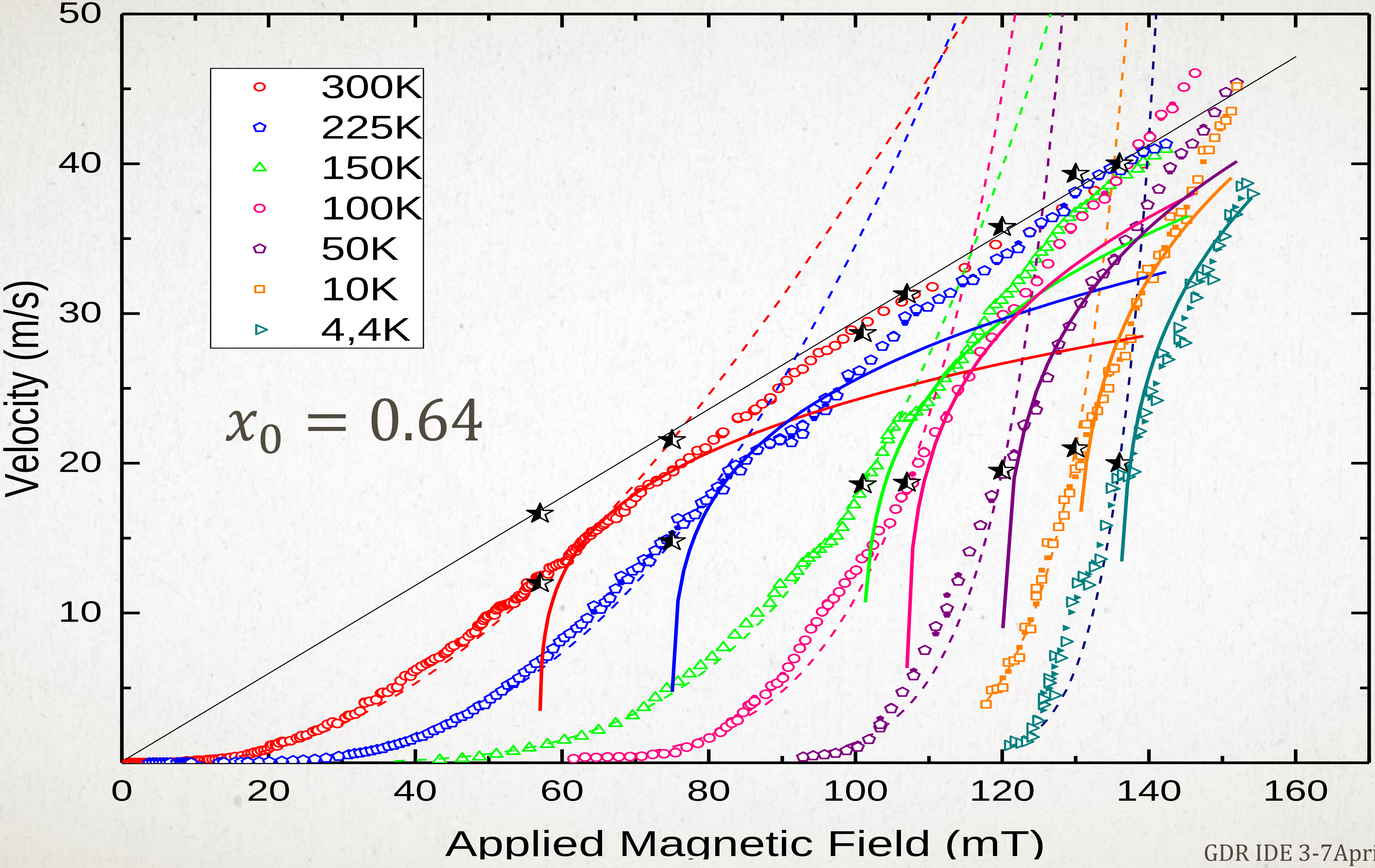
Meaning of v_H? Is v_H an extra non-universal parameter?

We introduce the ratio $x_0 = \frac{v_T}{v_H}$:

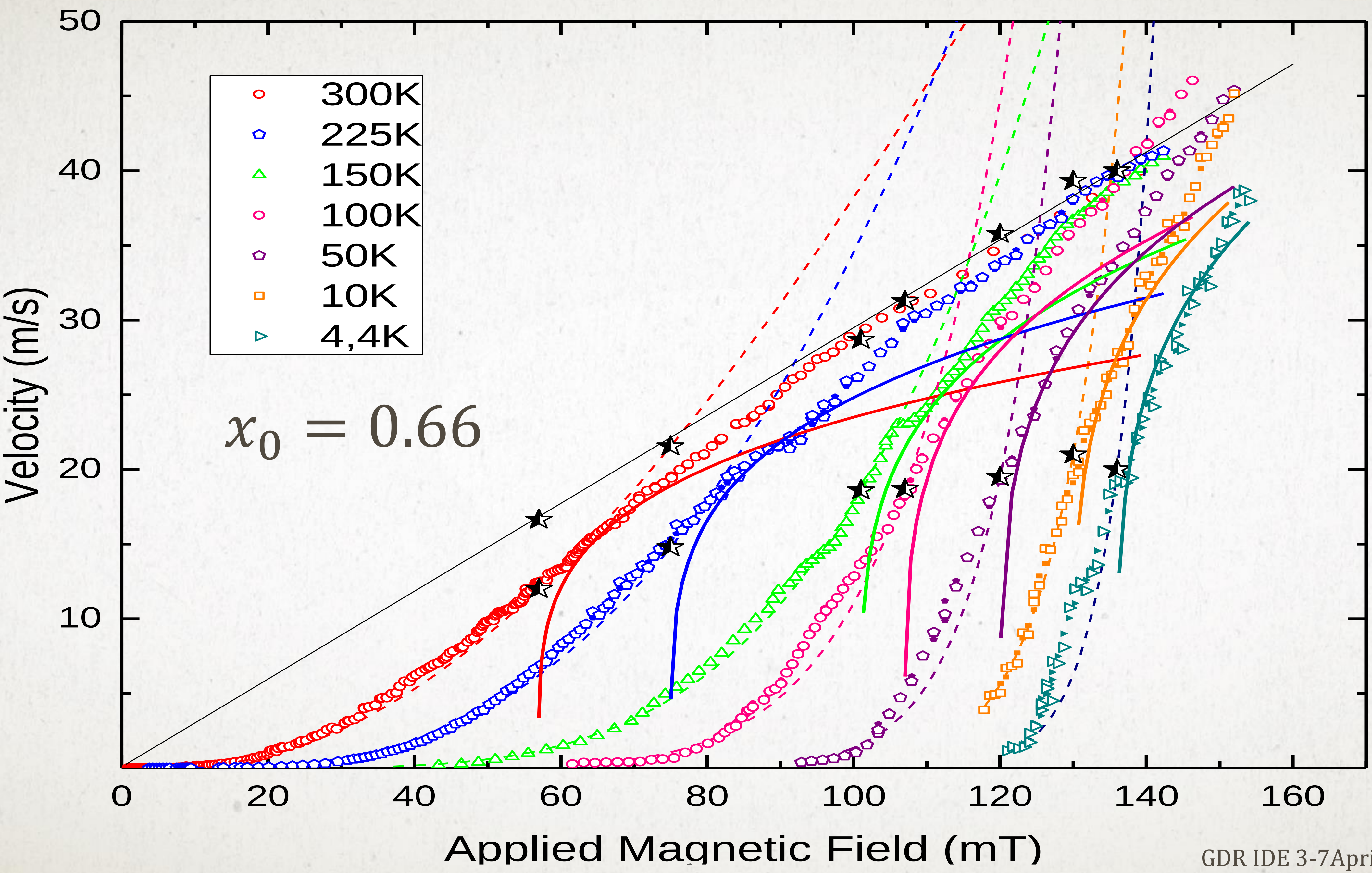
How does x_0 vary with H_d and T?



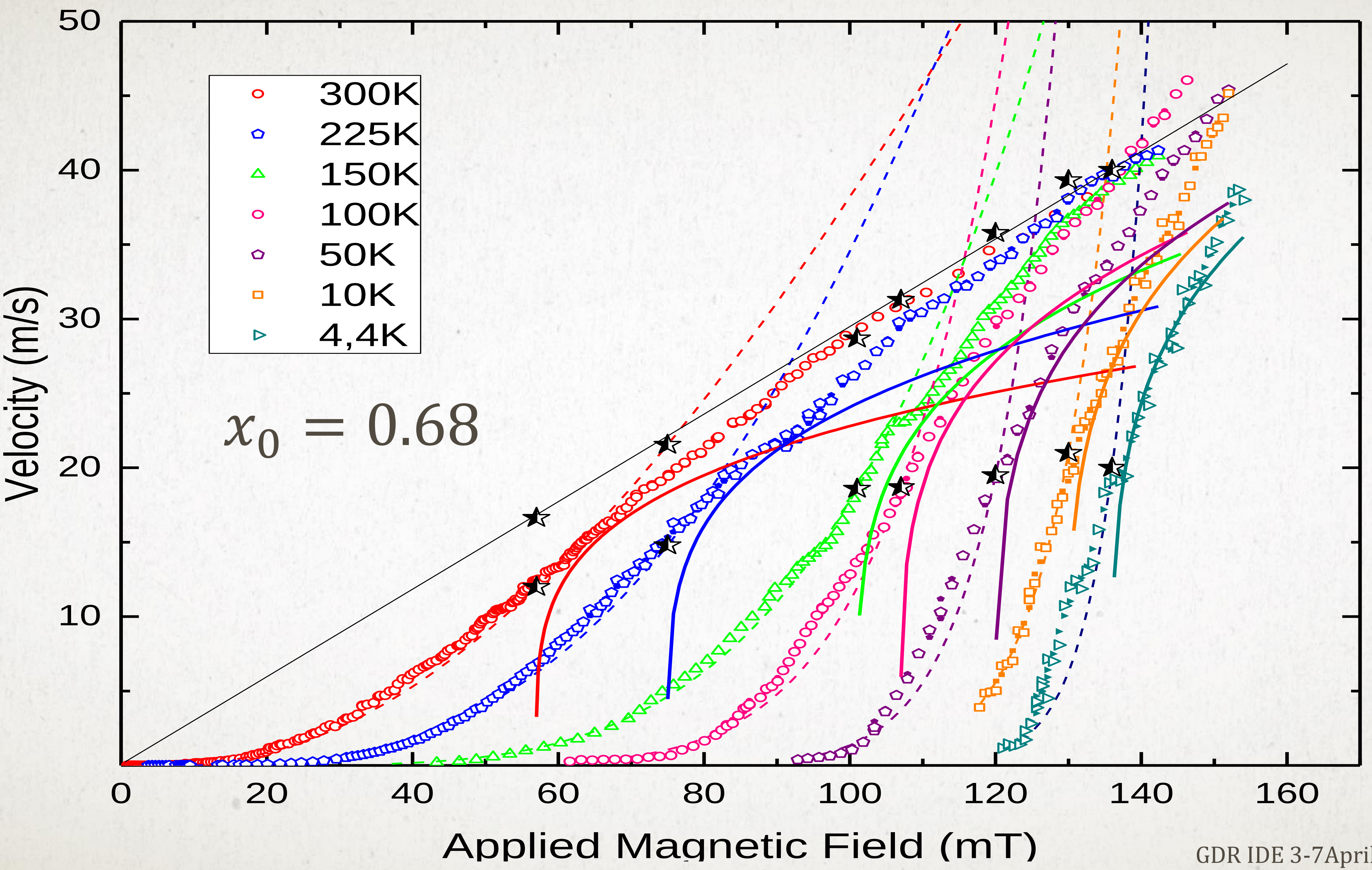
300K
225K
150K
100K
50K
10K
4,4K
$x_0 = 0.62$
Velocity (m/s)
Applied Magnetic Field (mT)
0
10
20
30
40
50
0
20
40
60
80
100
120
140
160

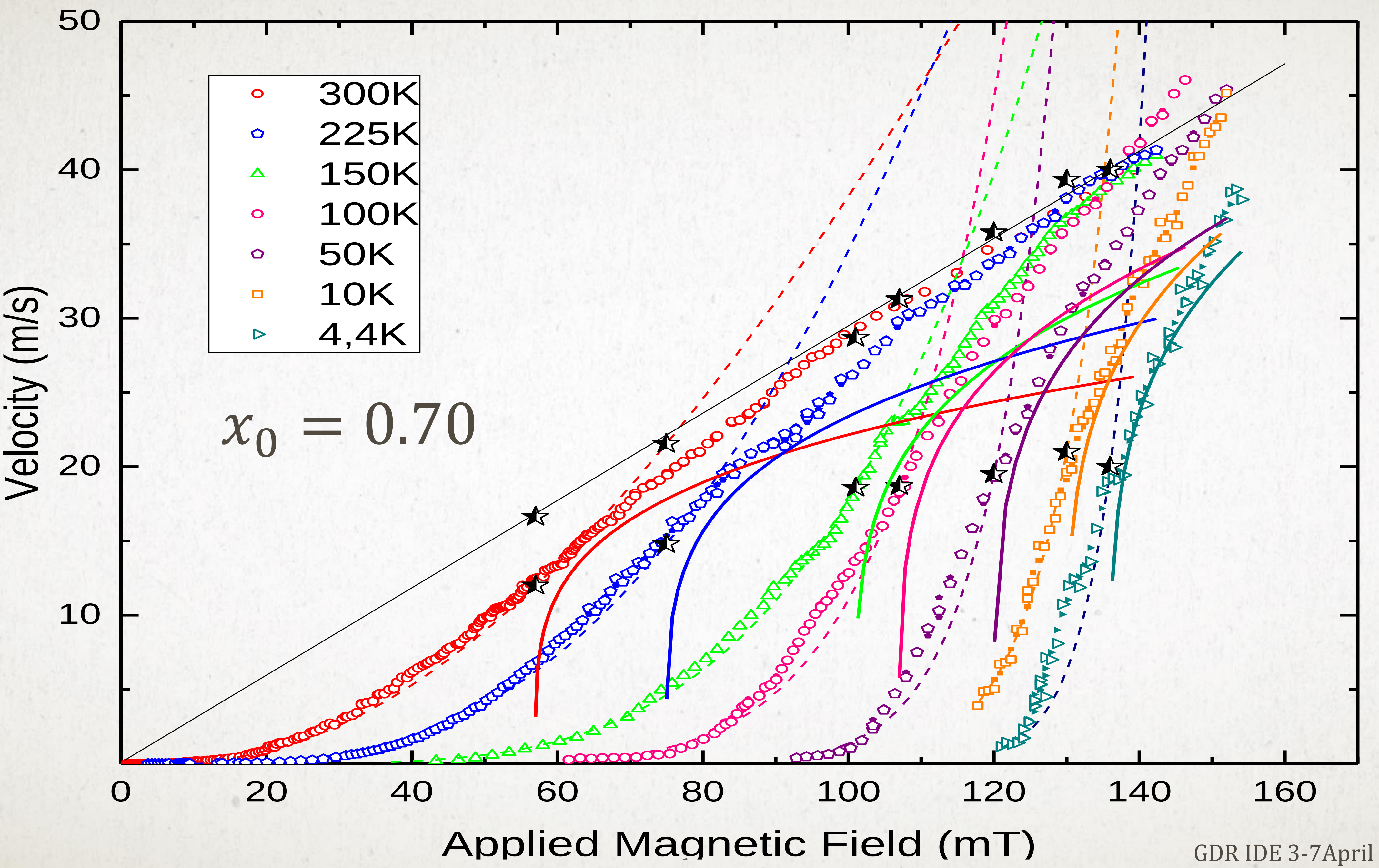


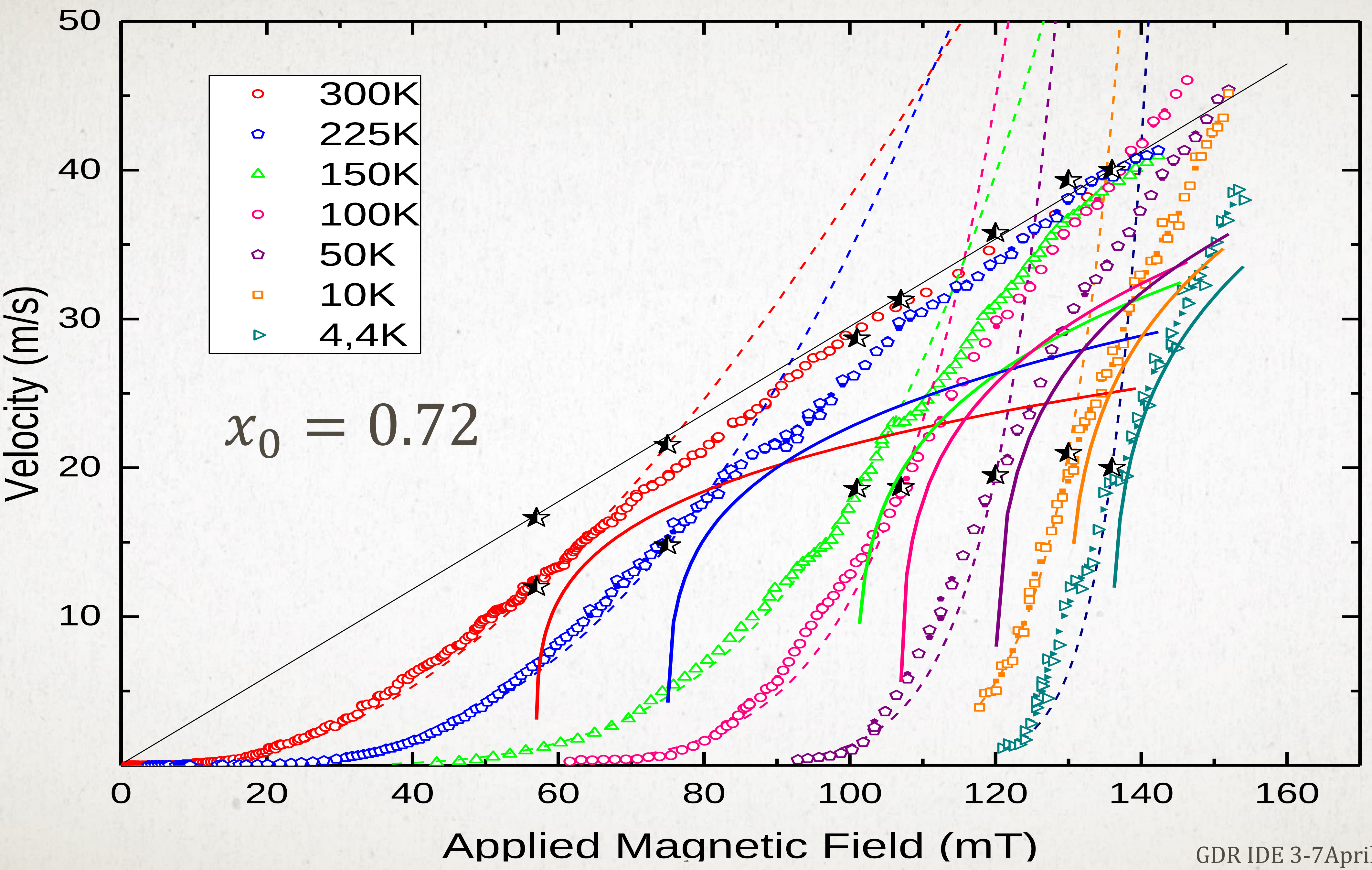
300K
225K
150K
100K
50K
10K
4,4K
$x_0 = 0.64$
Velocity (m/s)
Applied Magnetic Field (mT)
0
20
40
60
80
100
120
140
160
10
20
30
40
50



300K
225K
150K
100K
50K
10K
4,4K
Velocity (m/s)
Applied Magnetic Field (mT)
$x_0 = 0.66$

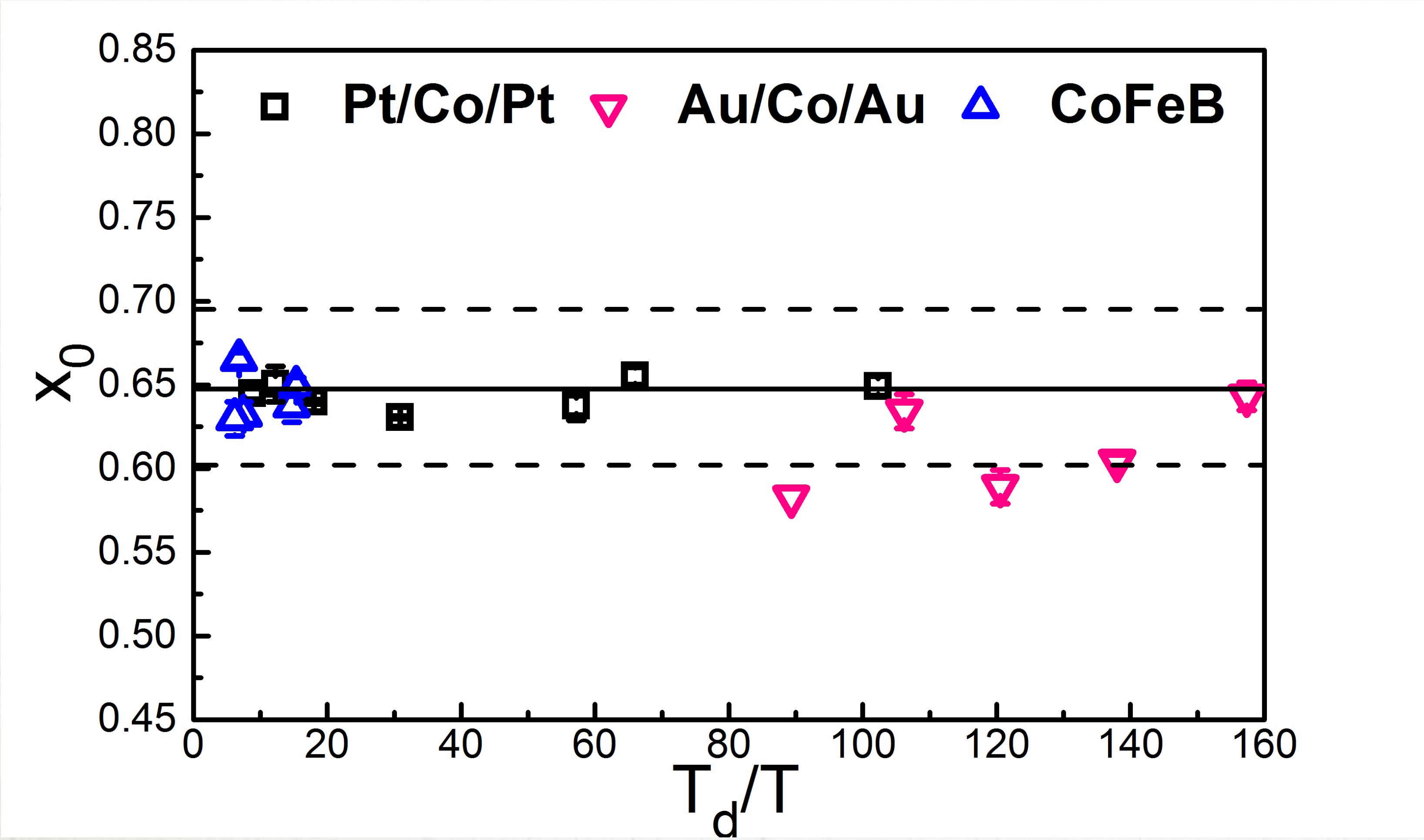

300K
225K
150K
100K
50K
10K
4,4K
$x_0 = 0.68$
Velocity (m/s)
Applied Magnetic Field (mT)
0
10
20
30
40
50
0
20
40
60
80
100
120
140
160


300K
225K
150K
100K
50K
10K
4,4K
$x_0 = 0.70$
Velocity (m/s)
Applied Magnetic Field (mT)
0
10
20
30
40
50
0
20
40
60
80
100
120
140
160



Velocity (m/s)
Applied Magnetic Field (mT)
300K
225K
150K
100K
50K
10K
4,4K
$x_0 = 0.72$
0
20
40
60
80
100
120
140
160
10
20
30
40
50

Thermal studies of the depinning transition



The ratio $x_0 = \frac{v_T(T)}{v_H(T)} = 0.65 \pm 0.02$
is independent of

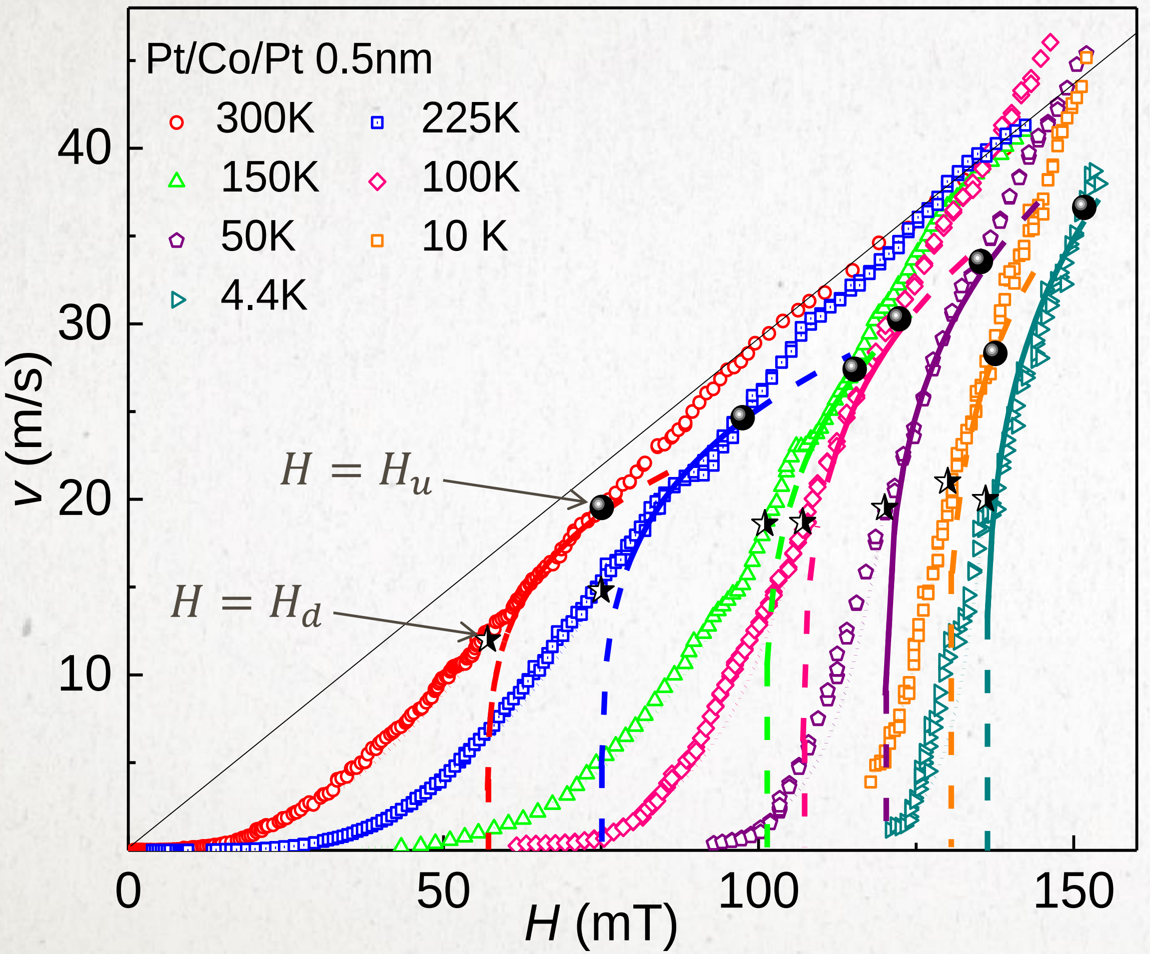
- temperature ($8 < \frac{T_d}{T} < 160$) and
- magnetic material.

$\Rightarrow$ **x_0 is a universal metric factor.**
(not predicted)

Consequence
Only 3 pinning parameters are controlling the depinning transition:
$T_d(T)$, $H_d(T)$, and $v_T(H_d, T)$

Thermal studies of the depinning transition

Boundaries of the depinning transition?



Upper limit:

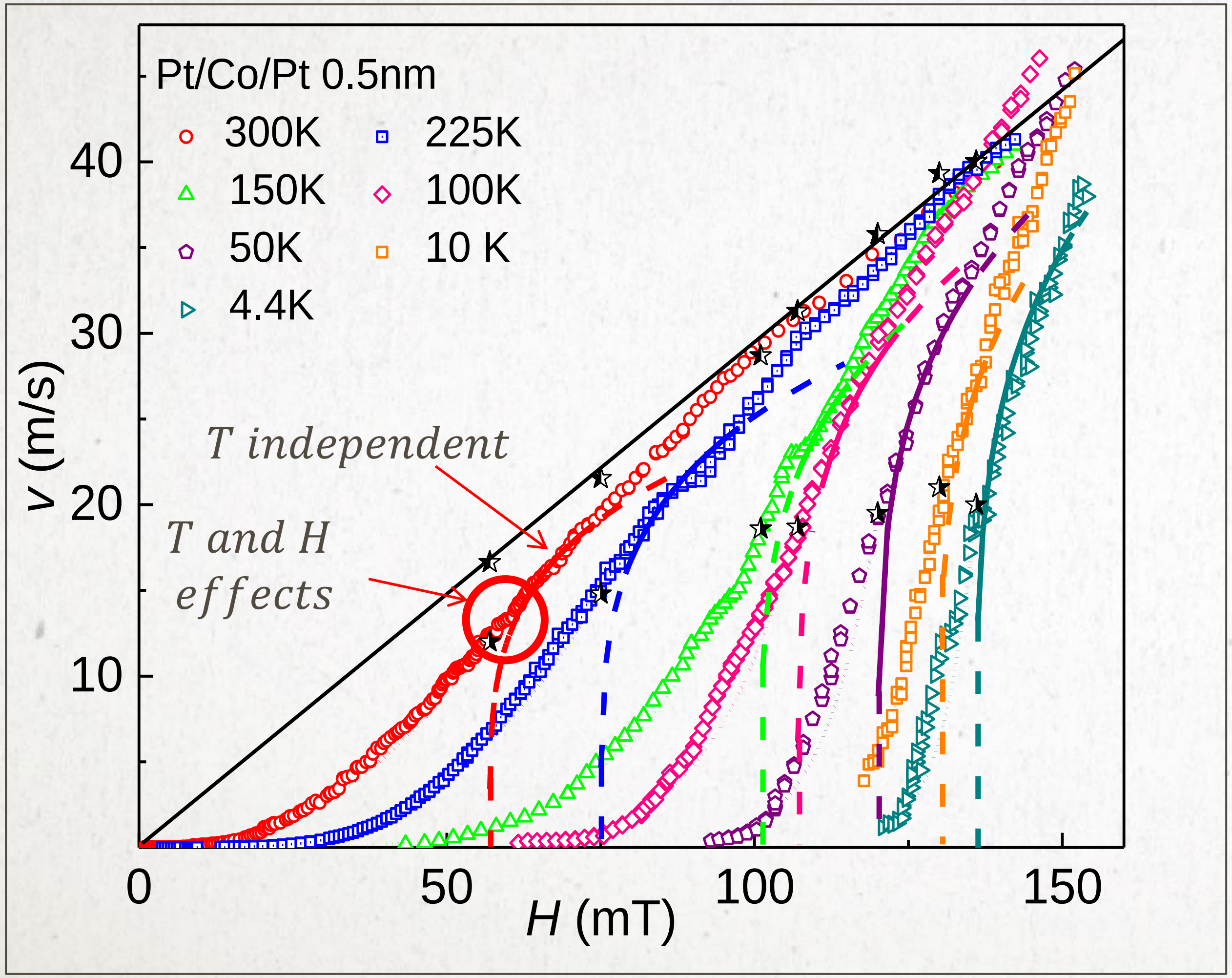
- Divergence between experimental results and the power law scaling $v \sim (H - H_d)^{\beta}$: $H = H_u$
- For $H < H_u$, DW motion is independent of its texture
- For $H \geq H_u$, DW motion is probably not universal

Lower limit:

H_d: lower (upper) boundary of the depinning (creep).
No crossover between creep and depinning

Thermal studies of the depinning transition

Universal function accounting for T and field effects?

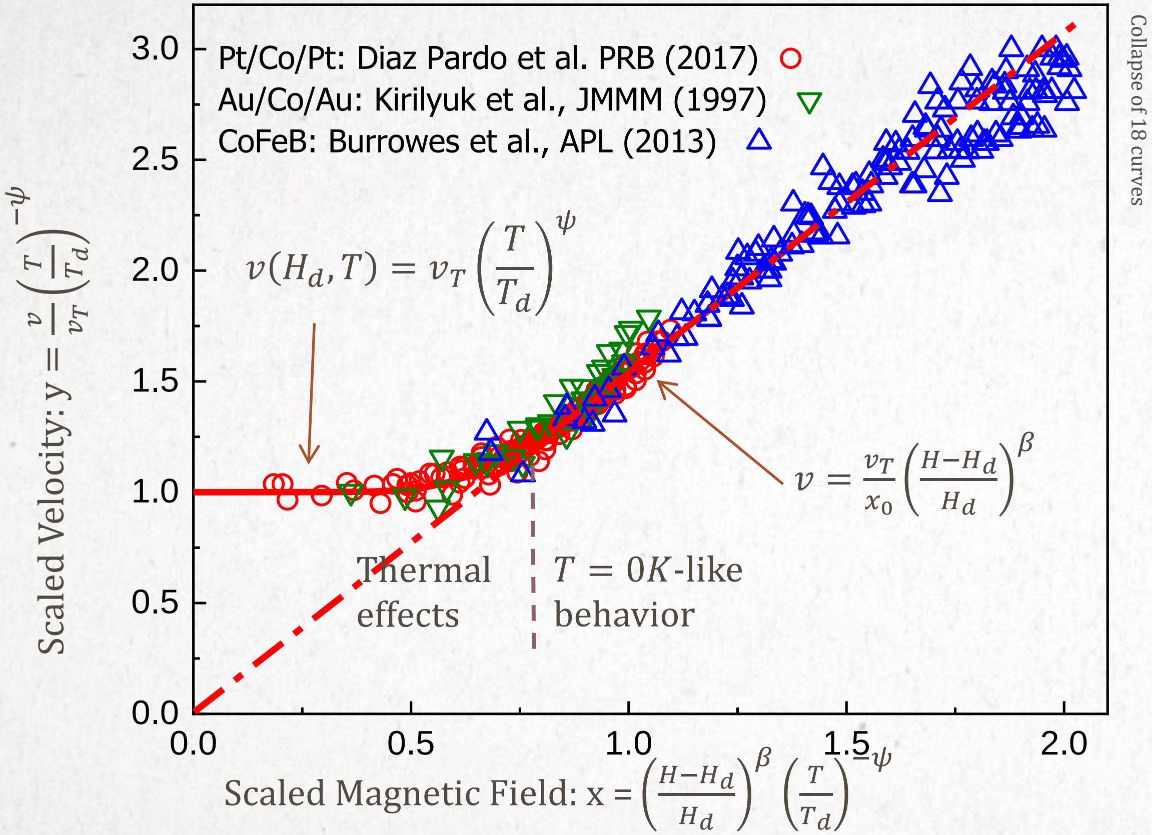


Two regimes of the depinning transition:
- Close to H_d, combined thermal and drive effects.
- Close to H_u, athermal behavior.

Universal function: rescaling the velocity curves

- Scaled field: $x = \left(\frac{H-H_d}{H_d}\right)^{\beta}\left(\frac{T}{T_d}\right)^{-\psi}$
- Scaled velocity: $y = \frac{v(H,T)}{v_T}\left(\frac{T}{T_d}\right)^{-\psi}$

Thermal studies of the depinning transition



Universal depinning function

Shape ≈ two asymptotic behaviors:

- for $x < 0.4$, $\mathbf{y} \approx \mathbf{1} = \frac{v(H,T)}{v_T(T)}\left(\frac{T}{T_d}\right)^{-\psi}$

- for $x > 0.8$, $\mathbf{y} \approx \frac{\boldsymbol{x}}{\boldsymbol{x_0}} = \frac{1}{x_0}\left(\frac{H-H_d}{H_d}\right)^{\beta}\left(\frac{T}{T_d}\right)^{-\psi}$

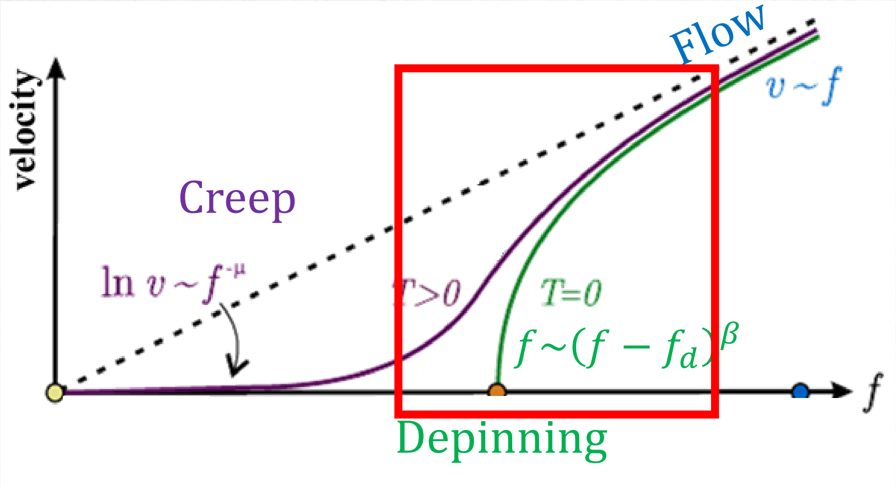
Contribution of thermal effects limited to a narrow range $x < 0.8$.
For $\frac{T_d}{T} \approx 10 - 100$: $\frac{H-H_d}{H_d} \leq 3 - 10\%$

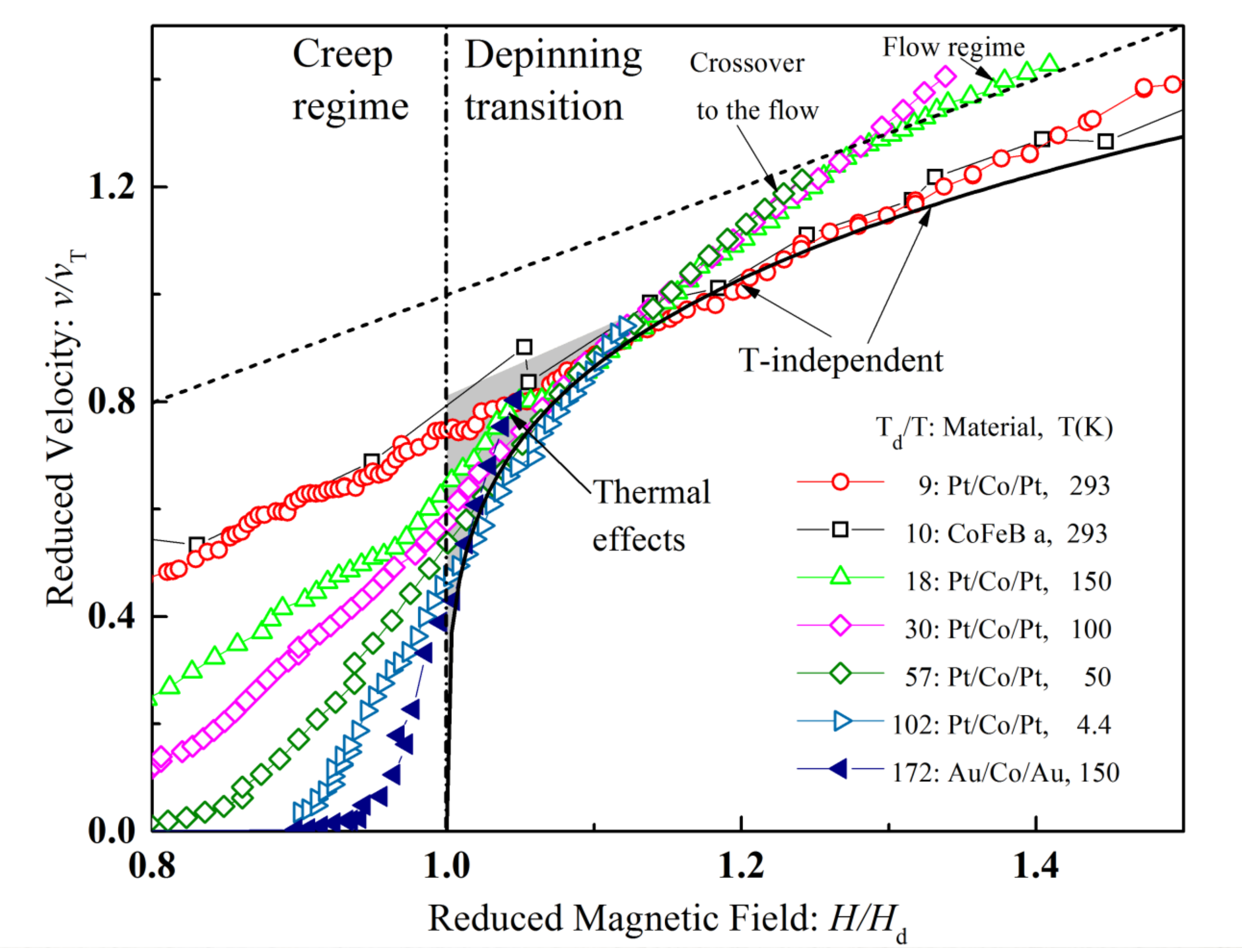
Upper limit

$x(H = H_u)$ is material and temperature dependent.

Thermal studies of the depinning transition

A close look at the thermal rounding of the depinning transition.



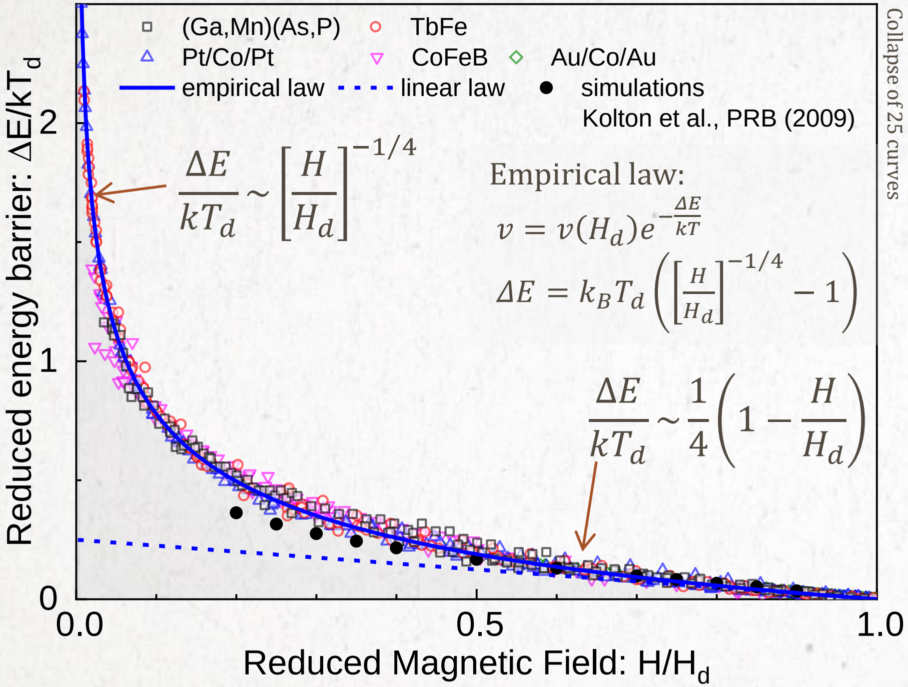


In the crossover to the flow, increasing contribution of DW magnetic texture.

The creep and depinning regimes

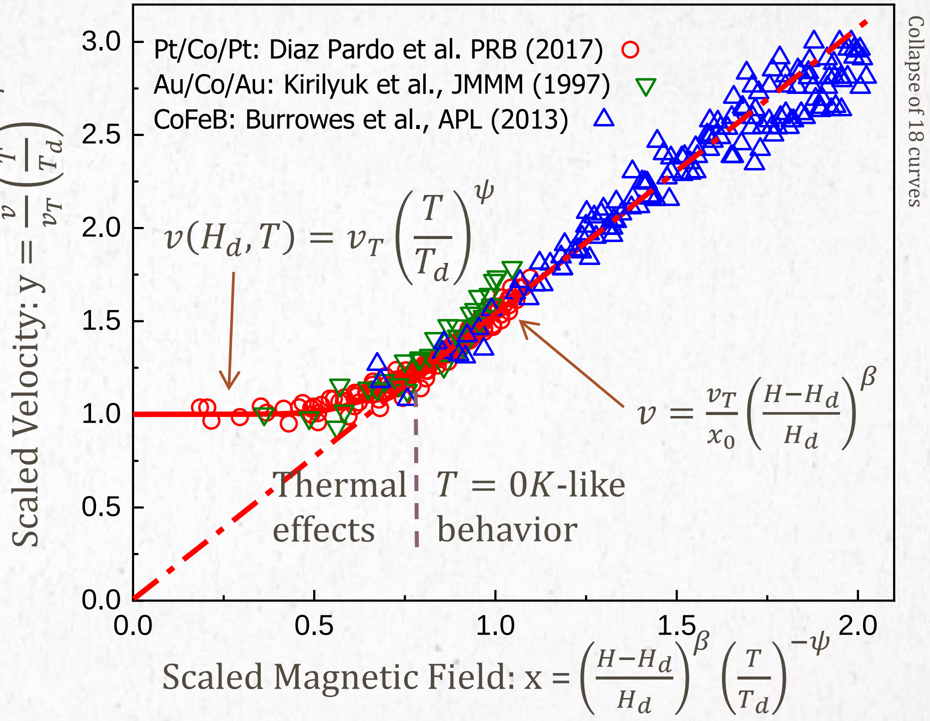
Creep motion: $H < H_d$

V. Jeudy et al., Phys. Rev. Lett. 117, 057201 (2016)



Depinning transition: $H \gtrsim H_d$

R. Diaz Pardo et al., Phys. Rev. B 95, 184434 (2017)



Non-universal and universal behaviors can be disentangled.

- universal functions describe the creep and the depinning transition
- material depend parameters: barrier height $k_B T_d$, depinning field H_d and velocity v_T

OUTLINE

1- INTRODUCTION TO DW STRUCTURE AND MOTION

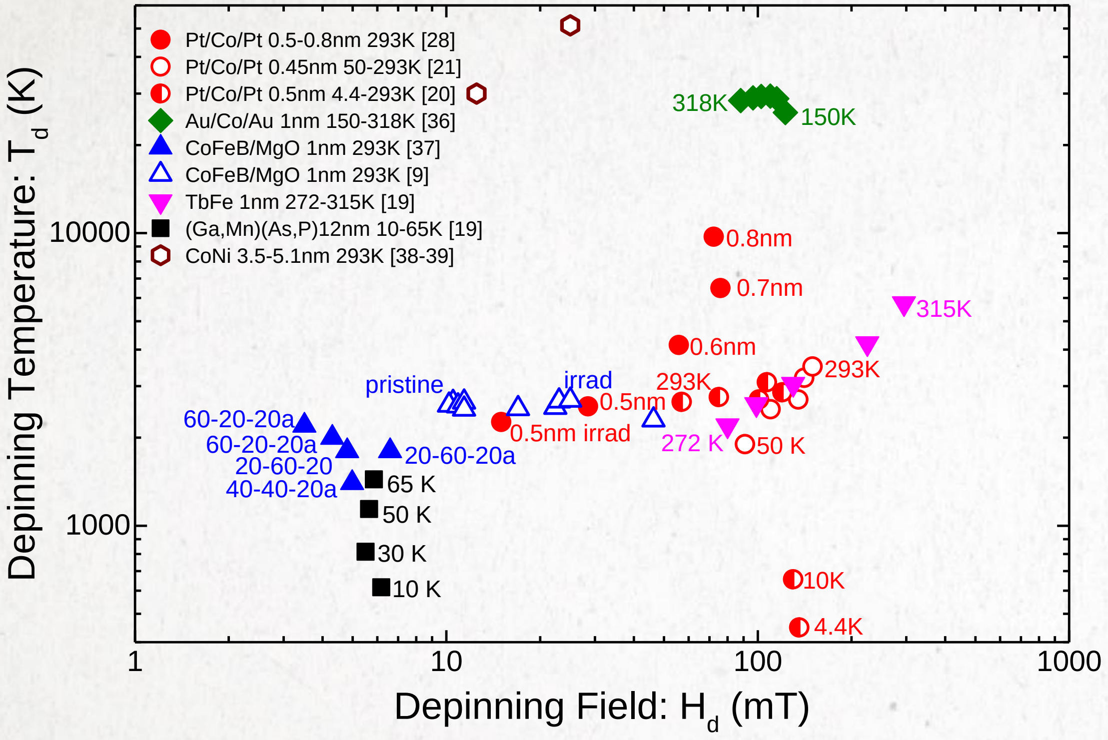
2- ANALYSIS OF CRITICAL BEHAVIORS

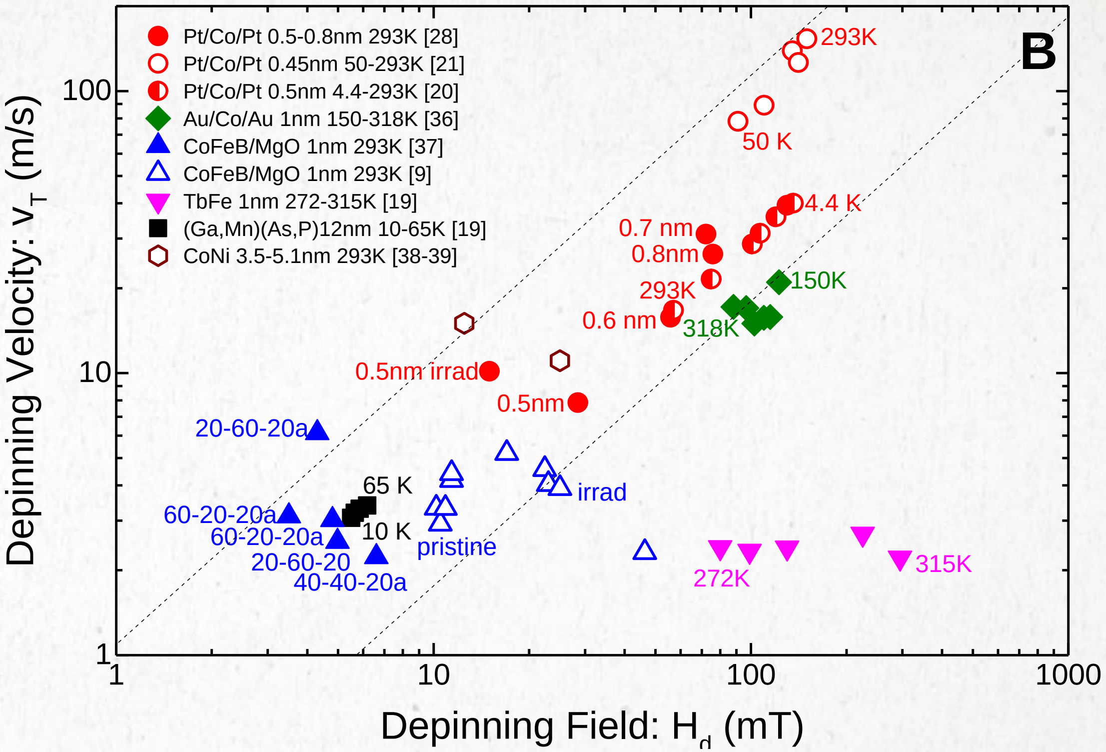
3- BEYOND ZERO DRIVE LIMIT AND POWER LAW SCALING
- Creep motion
- Depinning transition

4- MATERIAL DEPENDENT BEHAVIORS

Pinning dependent parameters

Maps of the pinning parameters



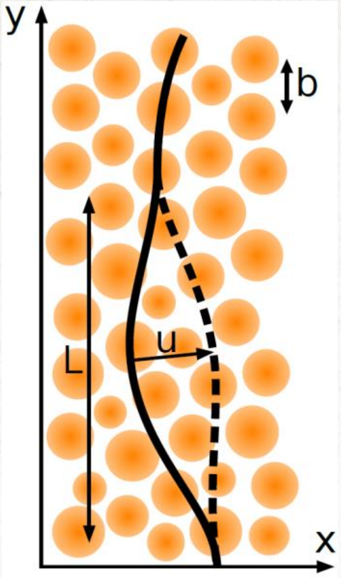


New : Quantitative comparison of the contribution of pinning to DW dynamics in different materials

Open questions

- Physical meaning of the pinning dependent parameters : $\boldsymbol{H_d, v_T, T_d}$?
- How do they reflect the interaction between DW and disorder?

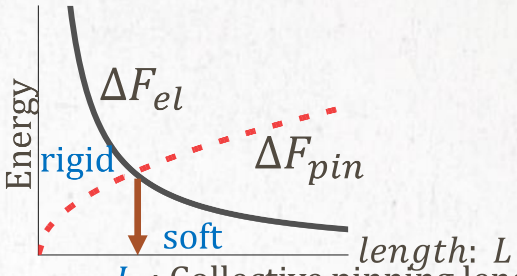
Energetic of a DW in a disordered medium



Energy contributions:
For a small displacement u of a segment of length L:

- Elastic energy: $\Delta F_{el} \sim \sigma t \frac{u^2}{L}$
- Pinning energy: $\Delta F_{pin} \sim \xi f_{pin} \sqrt{n \xi L}$
  pinning range: ξ and strength f_{pin}
- Zeeman energy: $\Delta F_Z \sim -2\mu_0 M_S H_z t L u$

Lemerle *et al.*, PRL ***80***, *849* (1998)



L_c: Collective pinning length

Scaling arguments for the depinning:
- The depinning ($H = H_d$) occurs when a rigid segment ($L \approx L_c$) can displaced over the distance $u \approx \xi$
- At the depinning, $\Delta F_{el} \sim \Delta F_{pin} \sim -\Delta F_Z$ with $\Delta F_{pin} \approx k_B T_d$

Jeudy *et al.*, PRB ***98***, *054406* (2018)

⇒DW-disorder interaction
- Range: $\xi \sim [(k_B T_d)^2/(2 M_s H_d \sigma t^2)]^{1/3}$
- Strength: $f_{pin} \sim \frac{1}{\xi \sqrt{n}} \sqrt{2 H_d M_s t k_B T_d}$ (scaling relations)

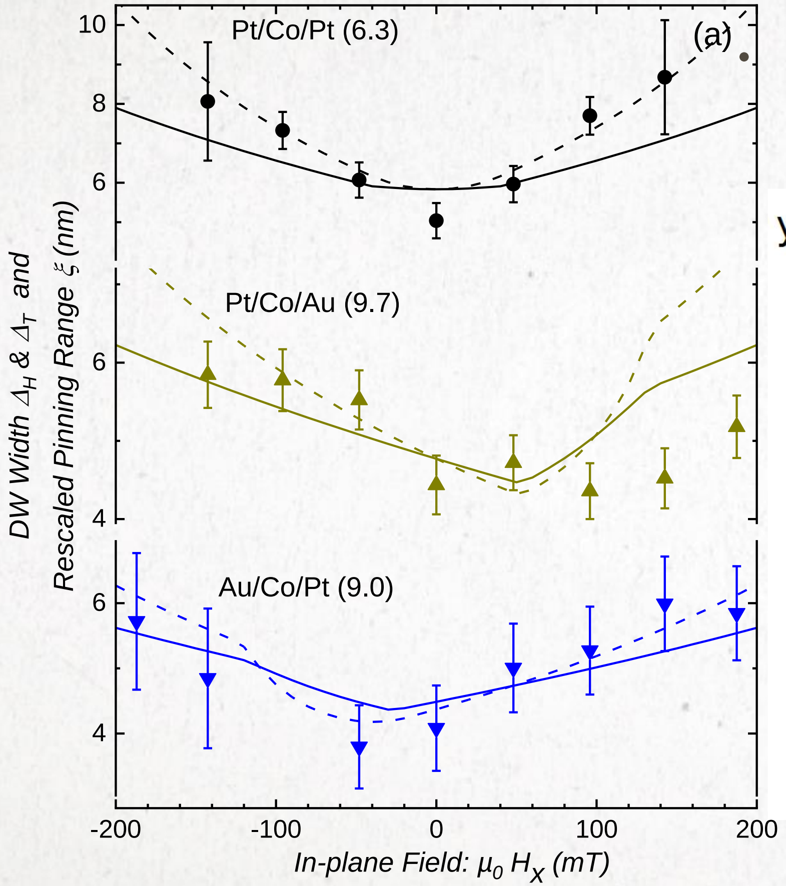
More accurate model:
Agoritsas et al. PRE **87**, 042406 (2013)

Methods
DW dynamics → $k_B T_d, H_d$
Measured micromagnetic parameters and model → M_s, σ, Δ
⇒ **interaction between DW and disorder: ξ, f_{pin}**

Exploring the domain wall pinning range: ξ

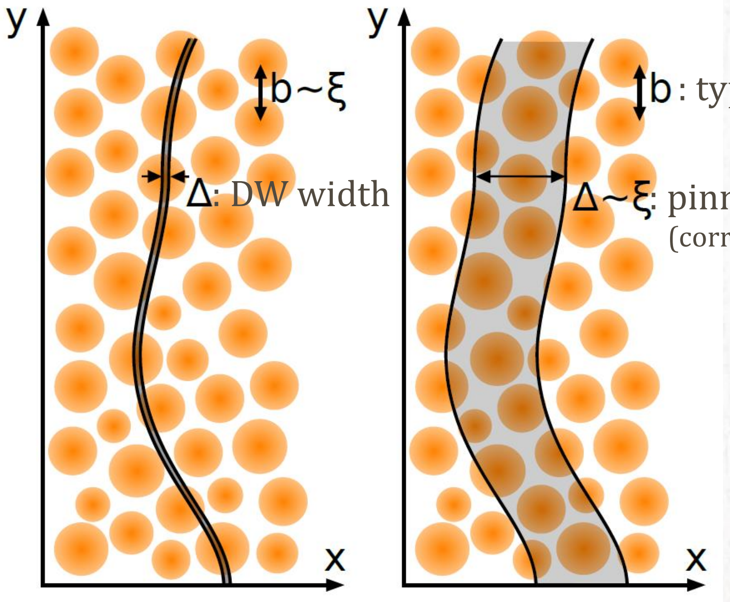
P. Gehanne et al., Phys. Rev. Res. **2**, *043134 (2020)*

Fixed disorder, an in-plane field modifies the DW texture (Δ and σ)



Δ_T: Thiele dynamics width and Δ_H Hubert geometrical width

Two possible scenarii for ξ: Natterman *et al.*, PRB **42** 8577 (1990)



b : typical size of pinning centers $\approx \frac{1}{\sqrt{n}}$

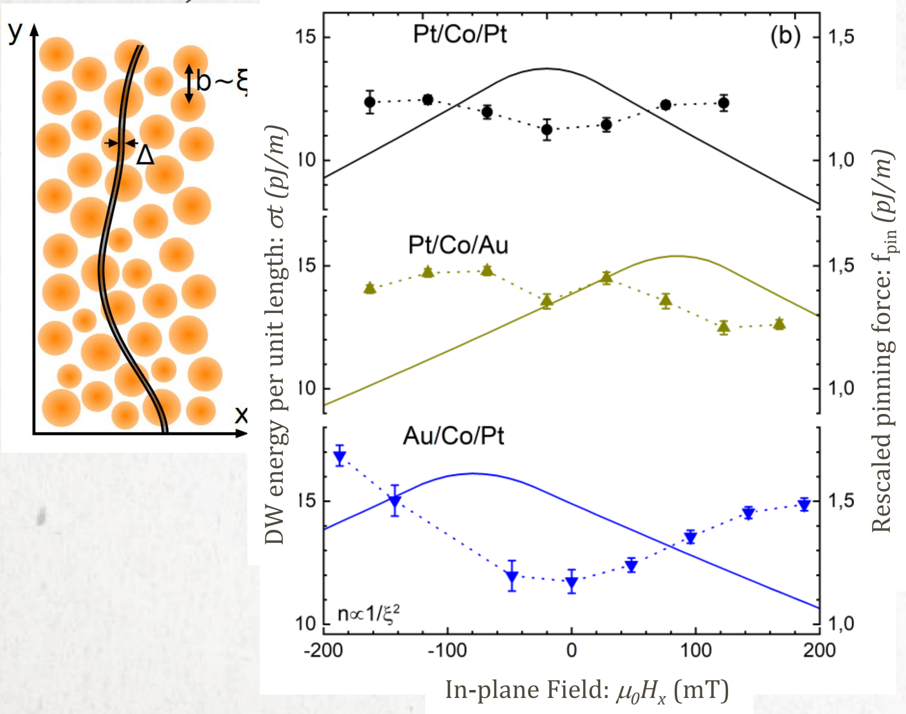
Δ~ξ: pinning range (correlation length of the disorder)

The correlation between the variations of the pinning range $\xi(H_x)$and of $\Delta(H_x)$ suggests that $b < \xi \sim \Delta$.

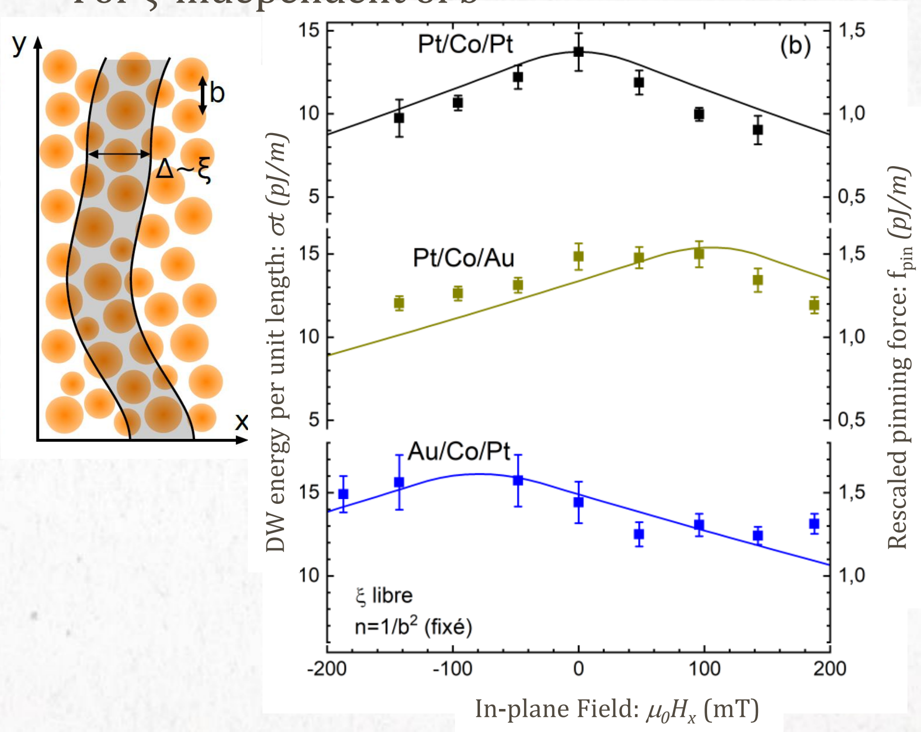
Domain wall pinning strength: f_{pin}

Comparison between the pinning strength f_{pin} and the DW energy σ

For ξ fixed $= b$



For ξ independent of b



The better correlations obtained for ξ indep. of b suggest: $\boldsymbol{b < \xi \sim \Delta}$ and $f_{pin} \propto \sigma$.
Different from the relation: $b \sim \xi$ assumed since Lemerle *et al.*, PRL (1998).

Results are not compatible with the assumption $k_B T_d H_d^{\frac{1}{4}} \sim \sigma^{1/4}$ of Je *et al.* PRB **88**, 214401 (2013)

Engineering DW pinning with light He+ ion irradiation

Origin of the variations of DW dynamics due to light He+ ion irradiations?

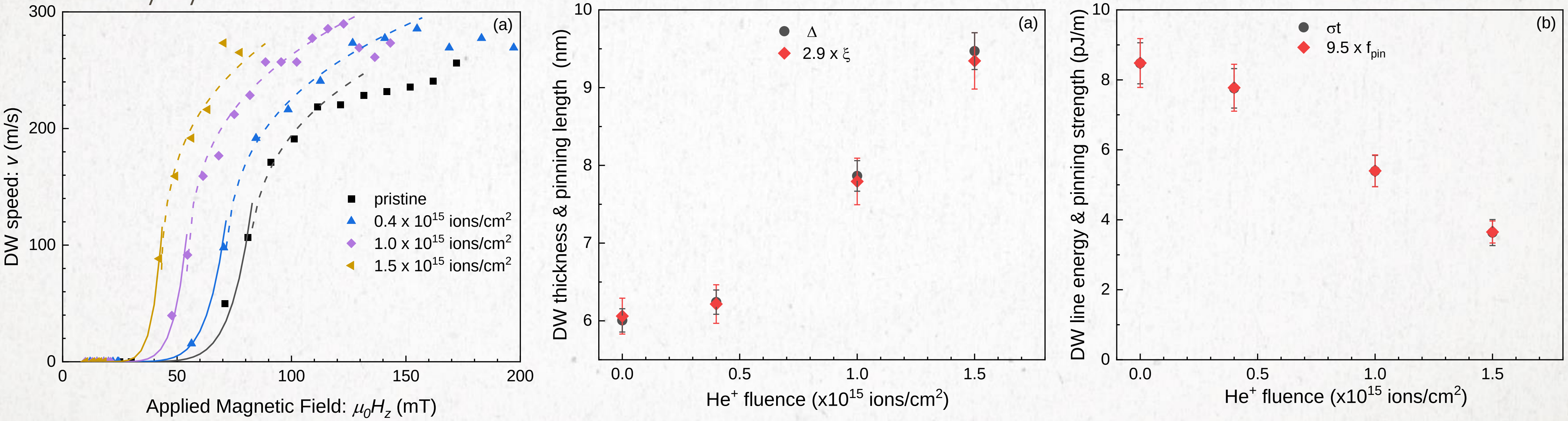
Balan *et al.*, arXiv:2303.04577
van Der Jagt et al., Phys. Rev. Appl. (2022)

Chappert *et al.*, Science (1998):
Devolder, Phys. Rev. B (2000)

irradiation ⇒ rearrangments of atoms over inter-atomic distances

Strong variations of the anisotropy K ⇒ of $\Delta \sim \sqrt{A/K}$

- Pt/Co/AlOx ultrathin films



Correlation between Δ and the pinning range ξ ⇒
The change of DW speed is essentially due to the variation of DW magnetic texture and not by a change of the disorder.

CONCLUSIONS

Disentangling universal and non-universal behaviors

- is essentially based on the analysis of experimental results with power law predictions
- requires to introduce material dependent parameters and to analyse their meaning
- requires a careful determination of the boundaries between dynamical regimes.

A tentative minimalist “experimental” definition of a universal behavior could be: independent of temperature, material, and compatible with some predictions of minimal models… all this over the largest possible ranges.

Accessing to non-universal behaviors

- allows to classify quantitatively different materials (depinning force, velocity and T)
- opens the discussion of the interaction between interface and weak disorder.

Results obtained for domain walls in ferromagnets should be valid for other systems described by the quenched- Edward-Wilkinson model.