# Dynamics of interfaces with an internal degree of freedom

Vivien Lecomte[1], Stewart Barnes[1,2], Jean-Pierre Eckmann[3], Thierry Giamarchi[1]

[1]Département de Physique de la Matière Condensée, Genève
[2]Physics Department, University of Miami
[3]Département de Physique Théorique et Section de Mathématiques, Genève

Pont-à-Mousson – 18th March 2010

MaNEP SWITZERLAND

UNIVERSITÉ DE GENÈVE

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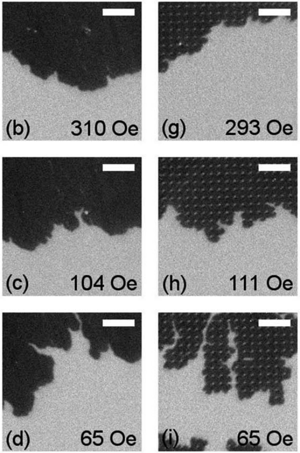
# Interfaces

Interfaces in magnetic films



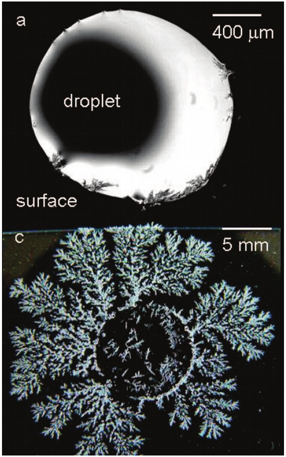

from Metaxas *et al.*

APL **94** 132504 (2009)

Large range of physical scales

Wide spectrum of phenomena

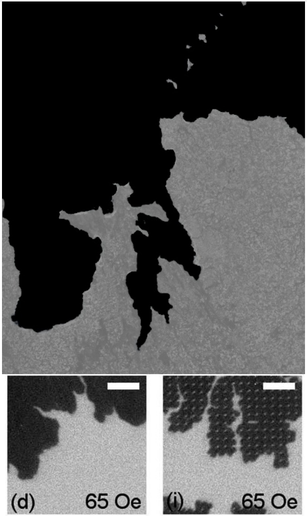
Crystal growth




from Shahidzadeh-Bonn *et al.*

Langmuir **24** 8599 (2008)

# Interfaces

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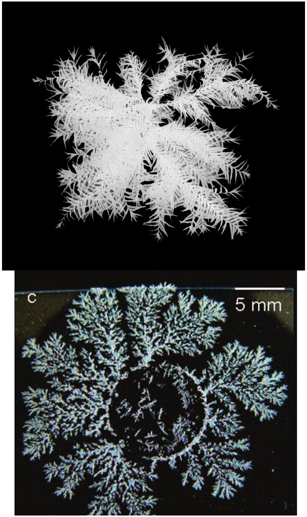


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# Disordered elastic systems

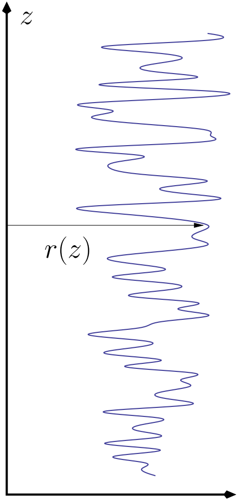
- Elasticity: tends to flatten the interface

$$\frac{c}{2}\int dz\,\left(\nabla r(z)\right)^2$$

- Disorder: tends to bend it

$$\int dz\, V\big(r(z),z\big)$$

Competition btw “order” and “disorder”

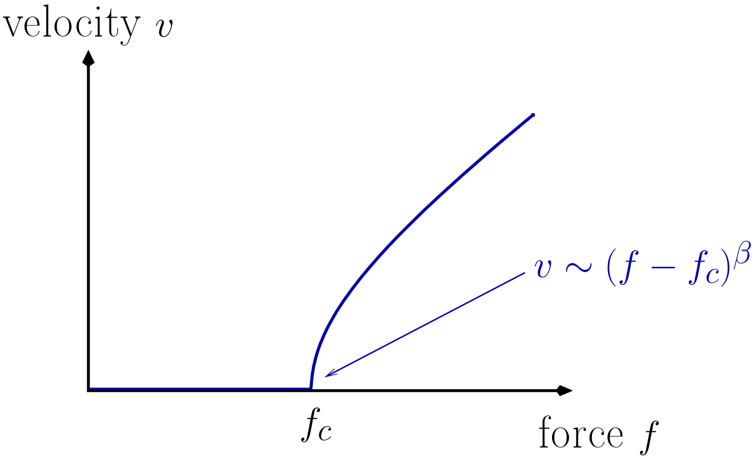


# Is $r(z)$ enough?

$\rightarrow$ Have a look to the dynamics of interfaces in simple examples.

# Depinning transition @ zero temperature

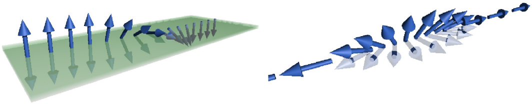
threshold force



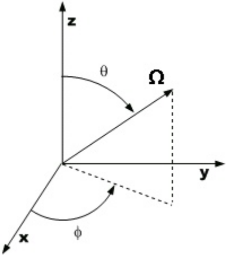
# Outline

1. Interface Physics
   - Systems
   - Depinning transition
2. Depinning with internal degree of freedom $\longleftarrow$
   - Modelisation
   - Dynamics

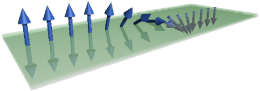
# Bulk model

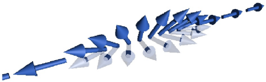


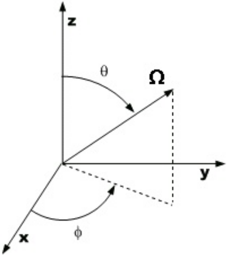
from Tatara *et al.*, J. Phys. Soc. Jap **77** 031003 (2008)



# Bulk model







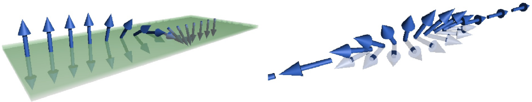

- Bulk energy

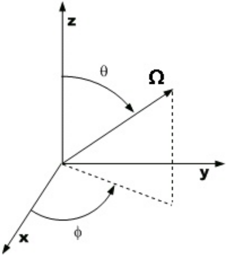
$$E = \int d^d x \left\{ J\Big[(\nabla\theta)^2 + \sin^2\theta(\nabla\phi)^2\Big] + K \sin^2\theta + K_\perp \sin^2\theta \cos^2\phi \right\}$$

- Equation of motion (Landau-Lifshitz-Gilbert)

$$\partial_t\Omega = \Omega \times \left(\frac{\delta E}{\delta\Omega} + f + \eta\right) - \Omega \times (\alpha\partial_t\Omega)$$

# Bulk model






- Effective equations

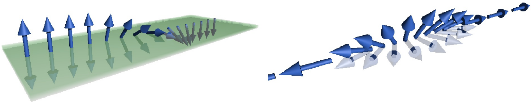
$$\alpha\partial_t r - \partial_t\phi = J\nabla^2 r \;+\; F_{\text{pinning}} \;+\; f_{\text{ext}} \qquad\qquad + \eta_1$$

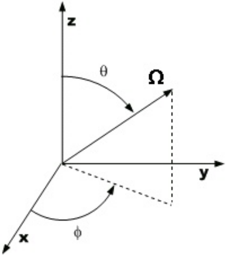
$$\alpha\partial_t \phi + \partial_t r = J\nabla^2 \phi \;-\; \frac{1}{2}K_\perp \sin 2\phi \qquad\qquad + \eta_2$$

- Effective model

Position $r(t)$ coupled to phase $\phi(t)$

# Bulk model






- Rigid wall approximation

$$\alpha\partial_t r - \partial_t \phi = \overbrace{-\cos\kappa r}^{\text{pinning}} + \overbrace{f}^{\text{external}} + \eta_1$$

$$\alpha\partial_t \phi + \partial_t r = -\frac{1}{2}K_\perp \sin 2\phi + \eta_2$$

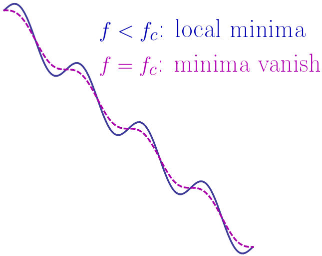
- Effective model

Position $r(t)$ coupled to phase $\phi(t)$

# Depinning @ zero temperature

**(1st case)** Large $K_\perp$: $\phi$ decouples from $r$

$$\alpha \partial_t r = f - \cos \kappa r$$



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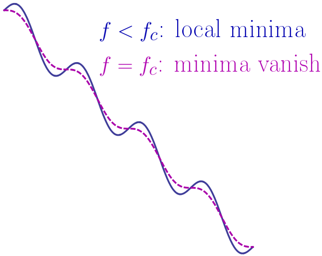
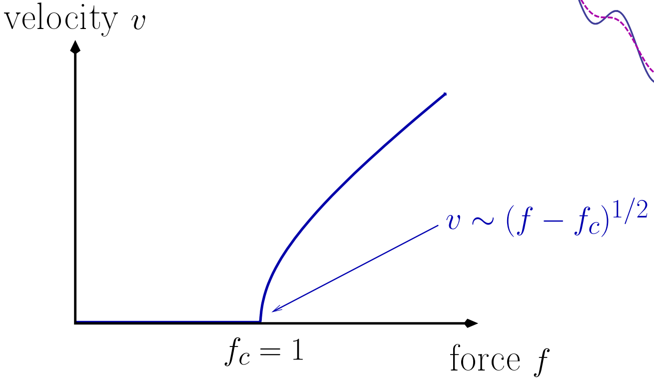
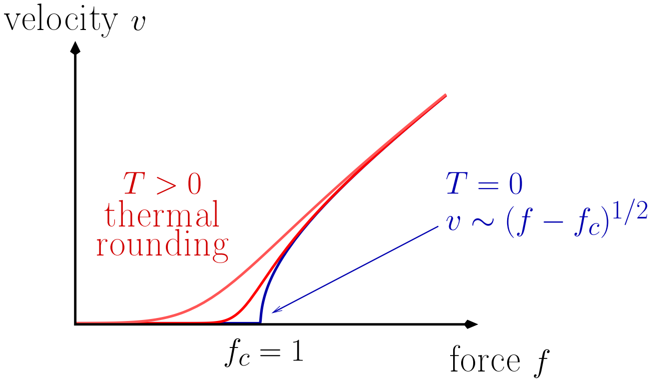


# Depinning @ finite temperature

**(1st case)** Large $K_\perp$: $\phi$ decouples from $r$

$$\alpha\partial_t r = f - \cos \kappa r + \eta$$



# Depinning @ zero temperature

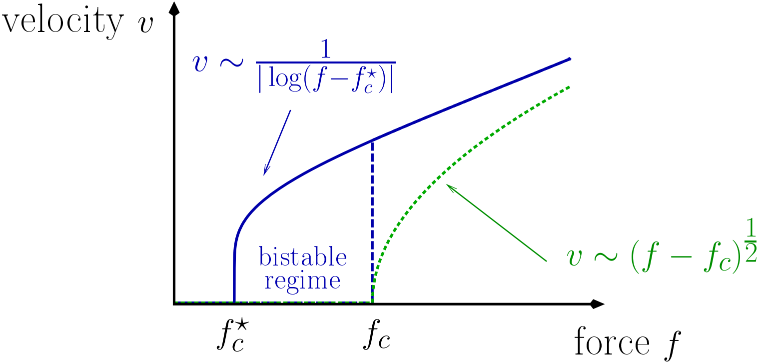
**(2nd case)** Small $K_\perp$: $\phi$ matters

$$\alpha\partial_t r - \partial_t\phi = f - \cos\kappa r$$
$$\alpha\partial_t\phi + \partial_t r = -\frac{1}{2}K_\perp \sin 2\phi$$

# Depinning @ zero temperature

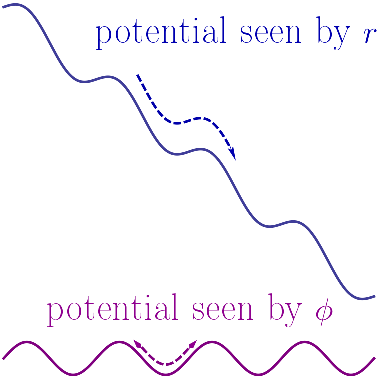
**(2nd case)** Small $K_\perp$: $\phi$ matters

- Dramatic change in the depinning law: $v \sim \frac{1}{|\log(f - f_c^\star)|}$

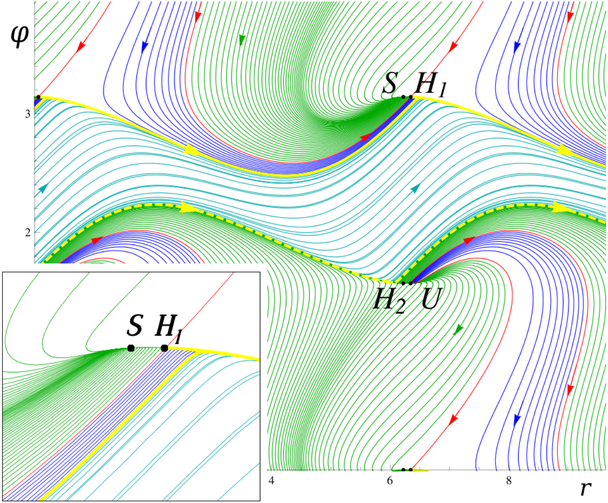



- Depinning at lower critical force: $f_c^\star < f_c$
- Bistability

# Physical interpretation



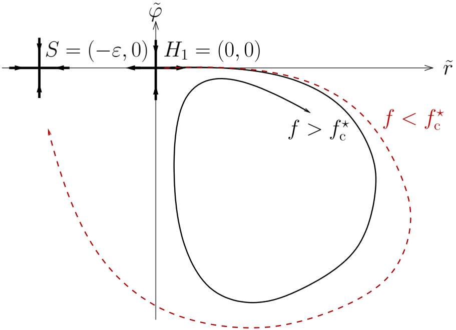
# Phase space




In the bistable regime ($f_c^\star < f < f_c$)

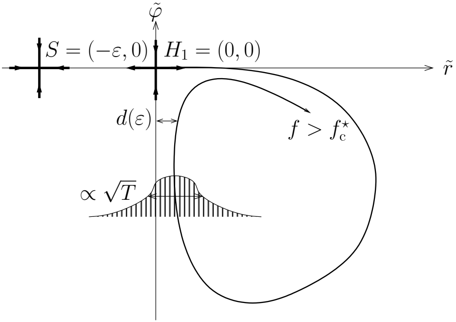
# Phase space

Homoclinic bifurcation: $(\epsilon \propto f_c - f)$



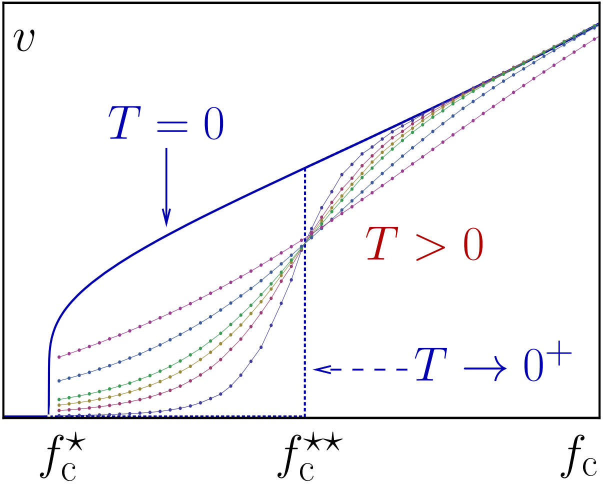
# Phase space: $T > 0$

Homoclinic bifurcation with noise: $(\epsilon \propto f_c - f)$



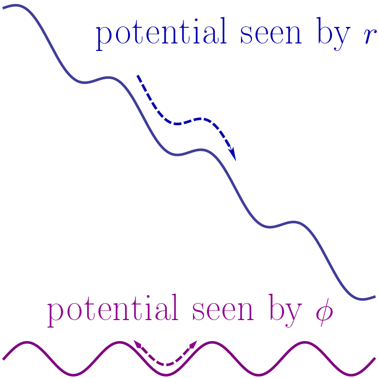

$$\text{escape time} \sim \underbrace{\exp\left(\frac{\epsilon^3}{T}\right)}_{\text{Arrhenius}} \underbrace{\exp\left(-\frac{A}{T} d(\epsilon)^2\right)}_{\text{Trapping probability}}$$

# Finite temperature




Force-velocity characteristics

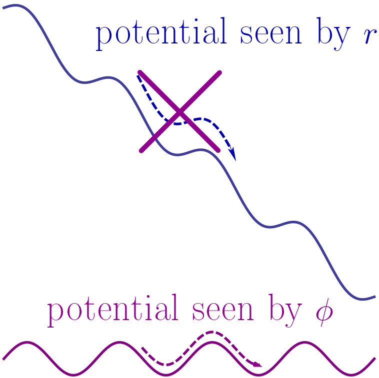
# This is not the end of the story




The phase $\phi$ plays the role of a 'momentum': helps to cross barriers
[see also Risken chap.11]

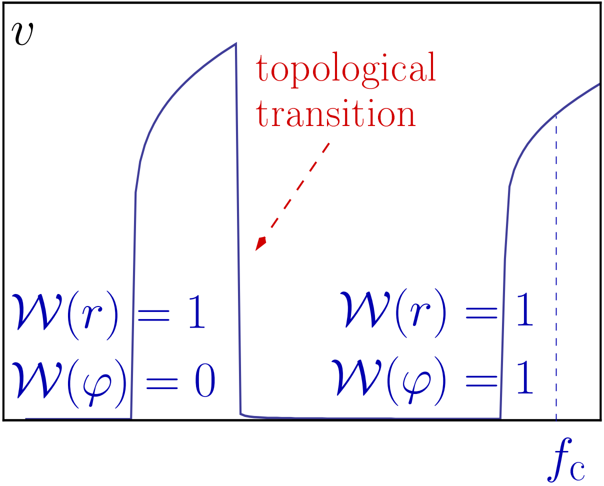
# This is not the end of the story

**(3rd case) Even smaller $K_\perp$**




inertia is unbounded whereas $\phi$ is bounded and periodic

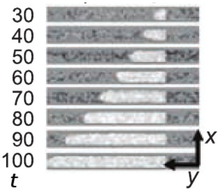
# Topological transition



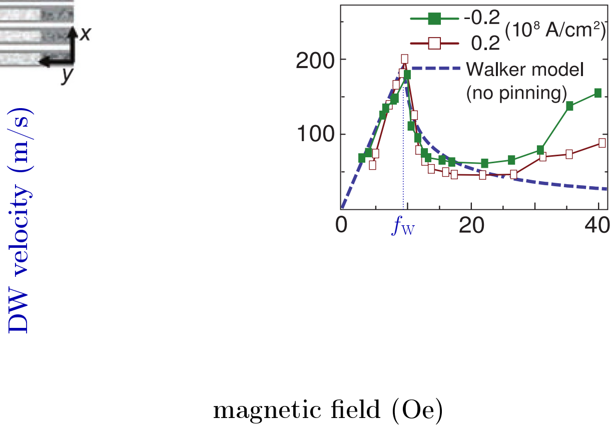

Successive regimes characterized by winding numbers $\mathcal{W}$

# Experiment

# SPINTRONICS

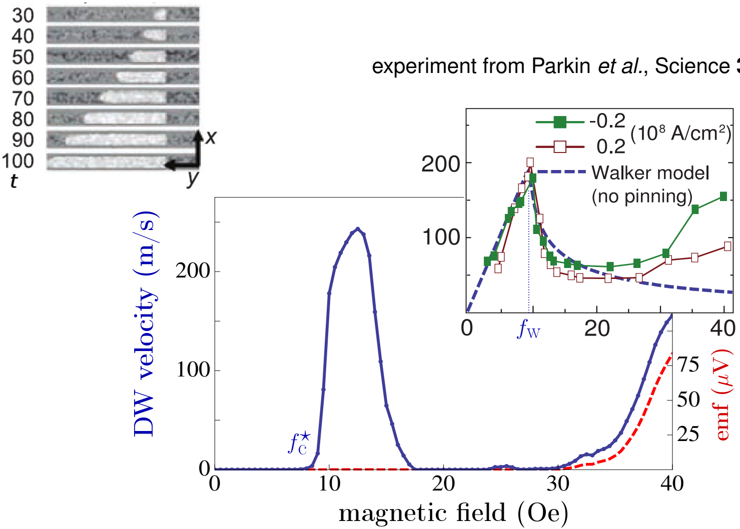



experiment from Parkin *et al.*, Science **320** 190 (2008)



# Experiment SPINTRONICS

experiment from Parkin *et al.*, Science **320** 190 (2008)

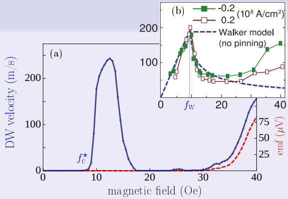


# Outlook

PRB **80** 054413 (2009)

## Internal degree of freedom

- unusual depinning law
- bistability
- non-monotonous $v(f)$ at finite T
- link with experiments




## Perspective

- Interface with elasticity ↔ modified creep law?
- Current driven wall
- Experiments ↔ periodic patterning?
- Other internal degrees ↔ coupled interfaces?

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PRB **80** 054413 (2009)

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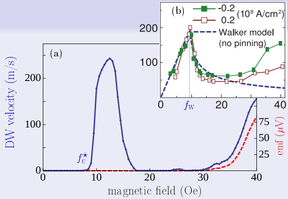


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