

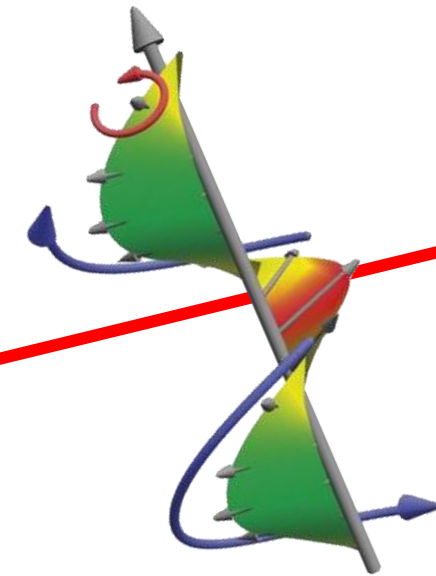
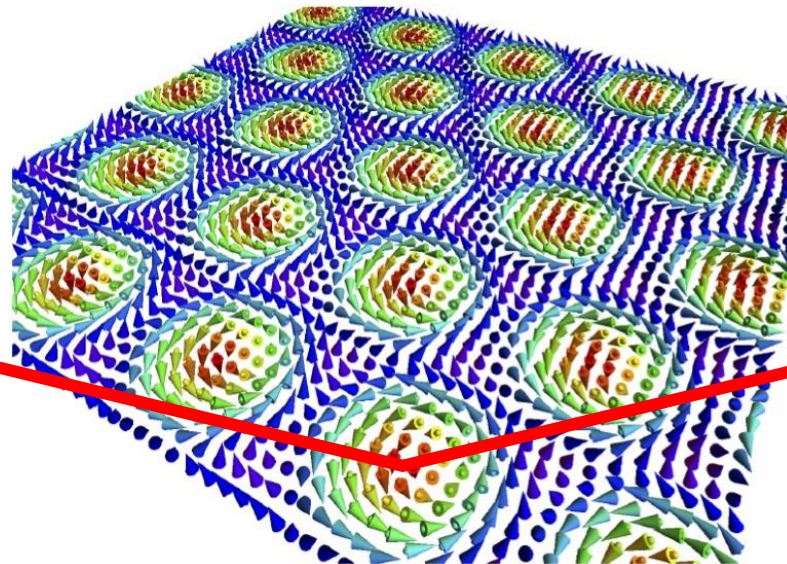
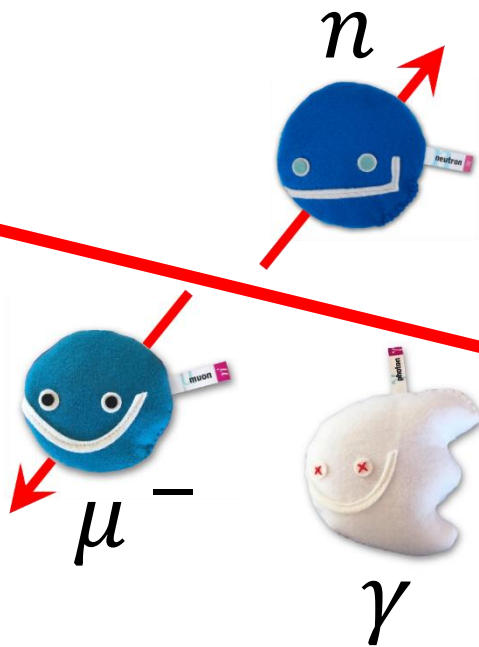
Nicolas MARTIN



université
PARIS-SACLAY

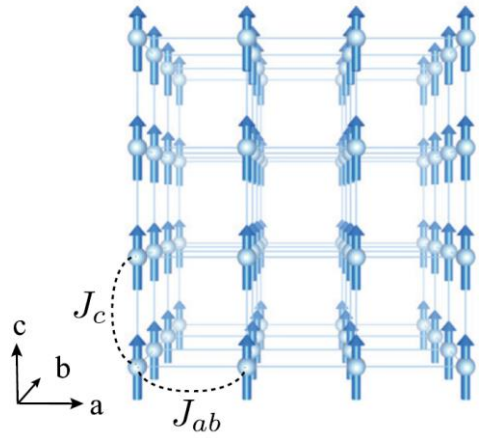


Textures et défauts topologiques magnétiques: propriétés statiques et dynamiques



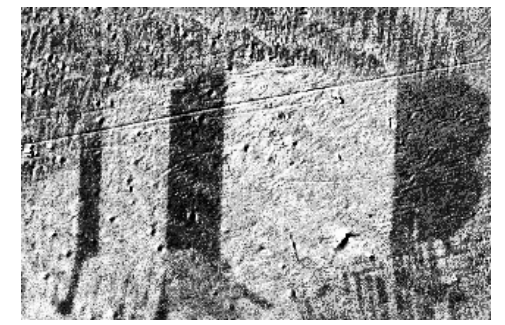
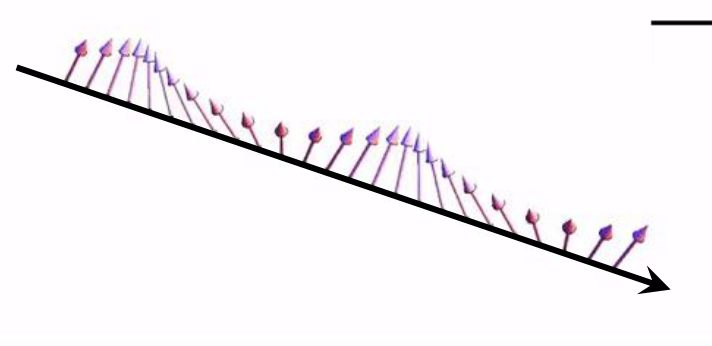
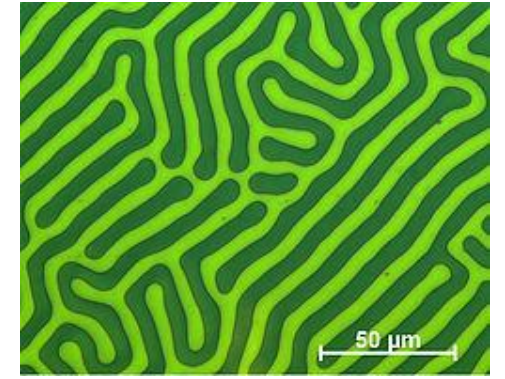
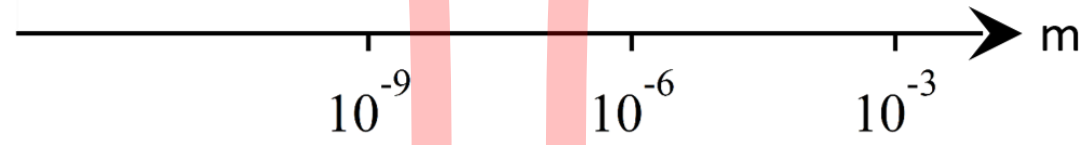
Audition concours CRCN 03/02 – 1^{er} Avril 2019

Echelles d'espace et de temps en magnétisme



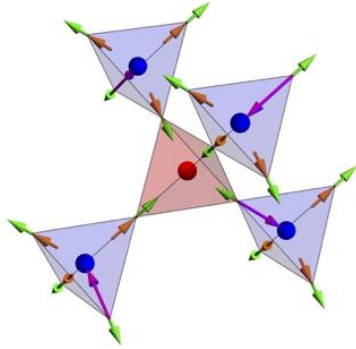
Microscopique
'Quantique'

Macroscopique
'Classique'

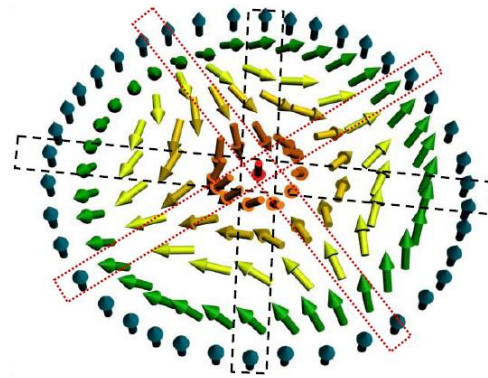


Le magnétisme à l'échelle mésoscopique: de nouveaux objets

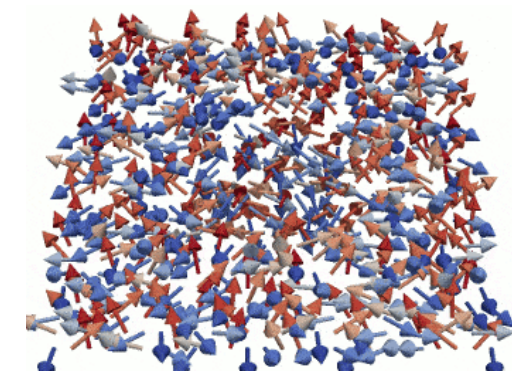
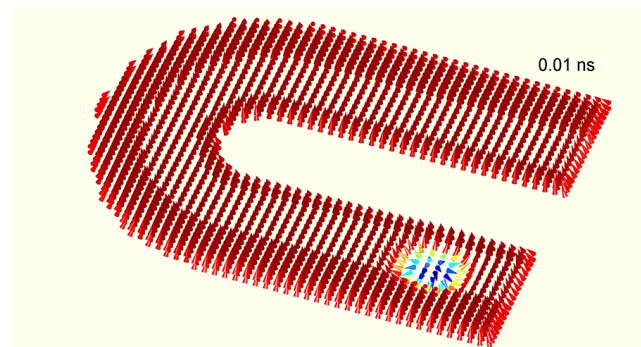
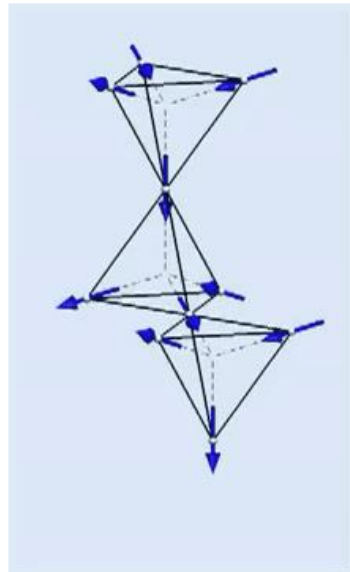
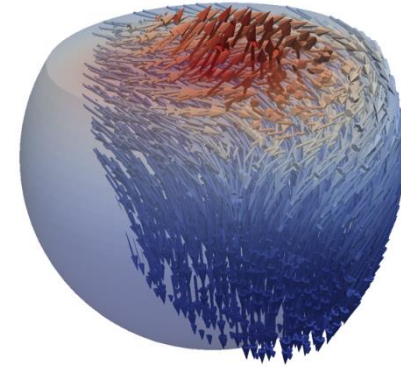
Monopoles



Skymions

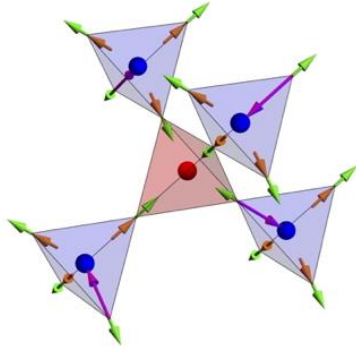


"Hérissons"

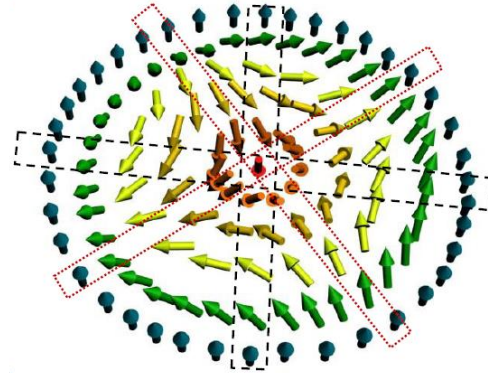


Le magnétisme à l'échelle mésoscopique: de nouveaux objets

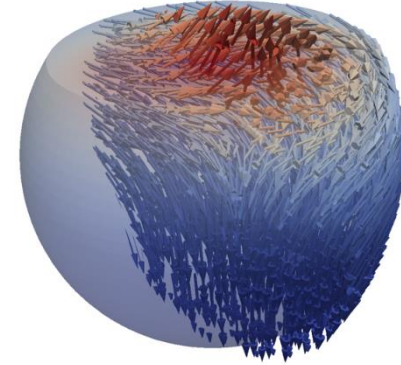
Monopoles



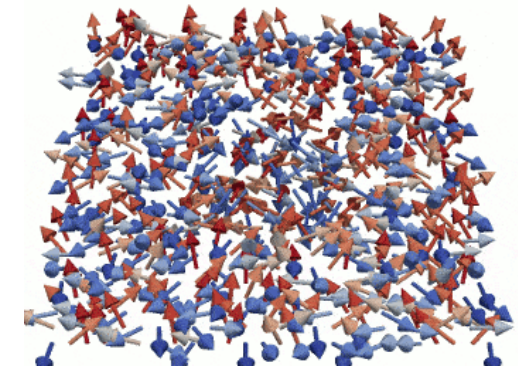
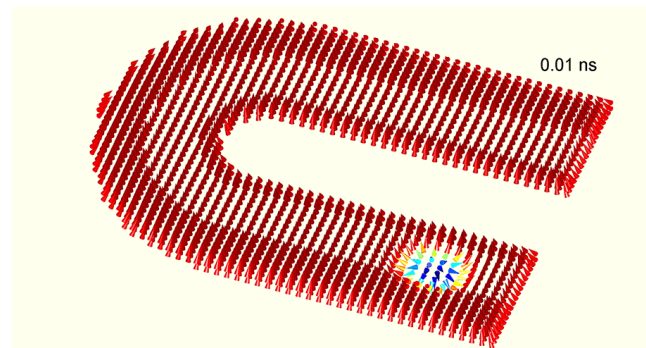
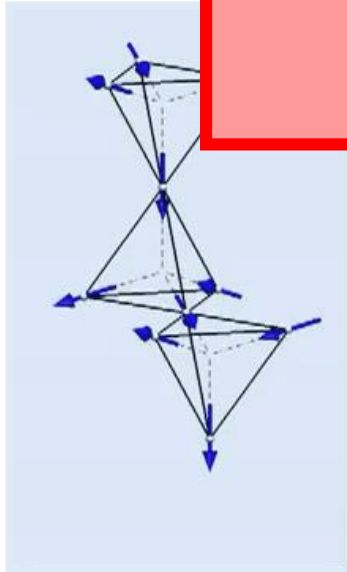
Skymions



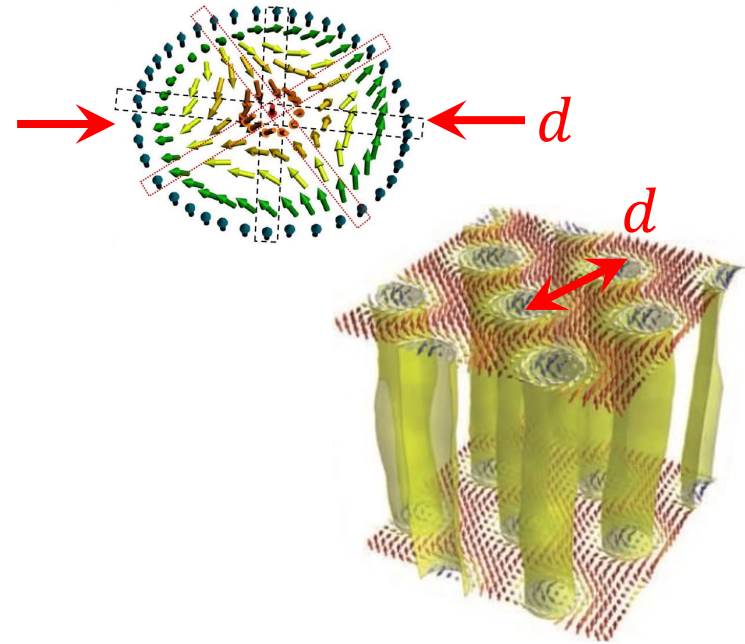
"Hérissons"



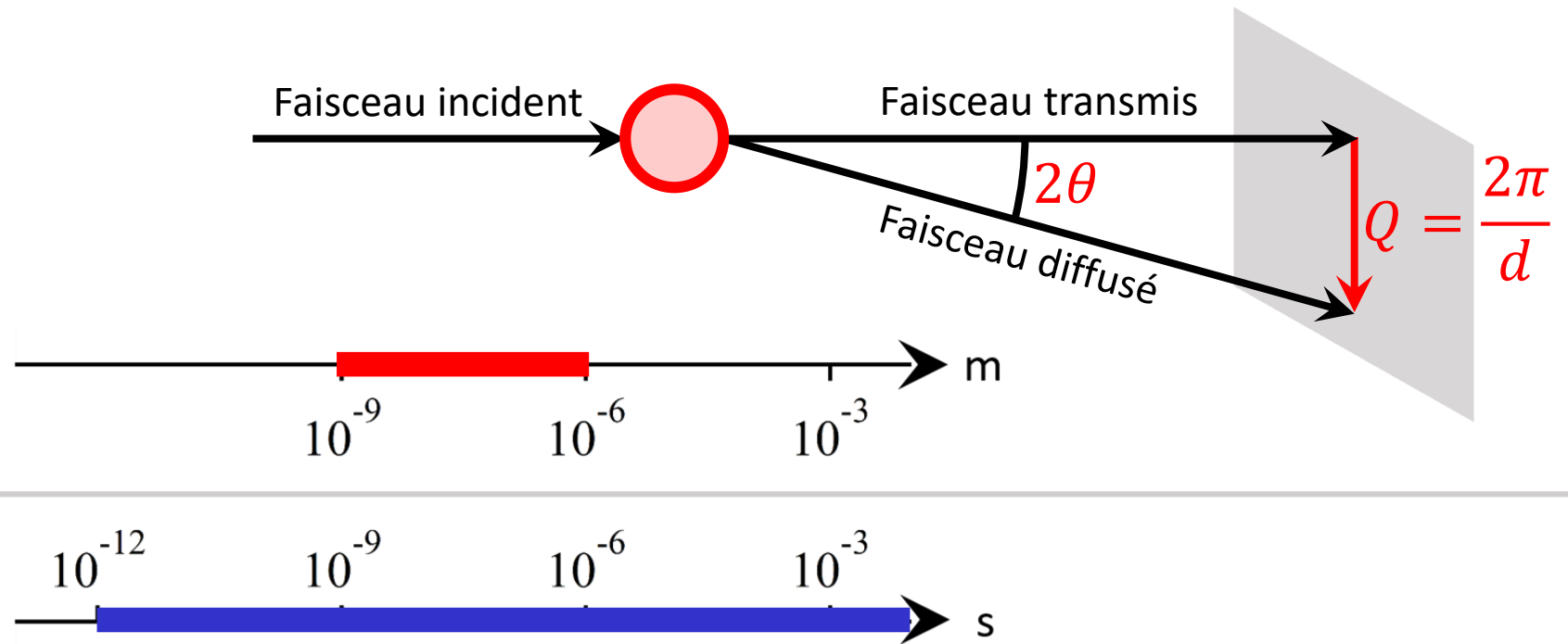
"There's plenty of room
in the middle!"



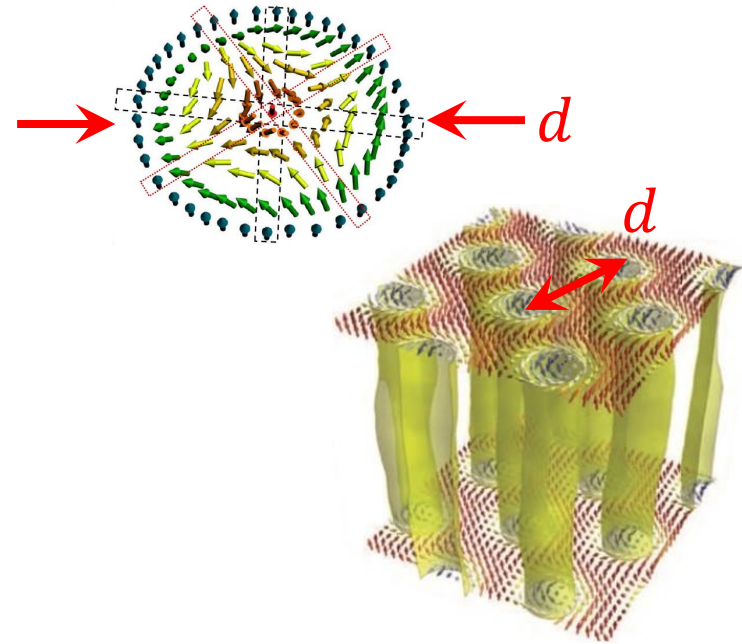
Le magnétisme à l'échelle mésoscopique: avec quels outils?



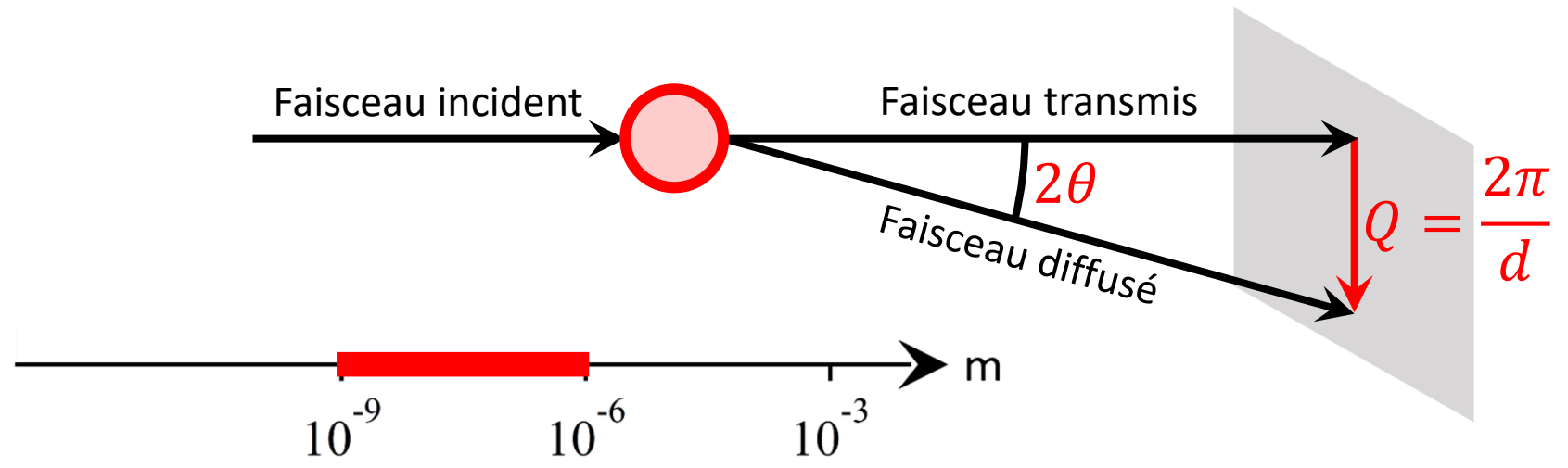
Diffraction de rayonnements aux petits angles (SANS/SAXS)



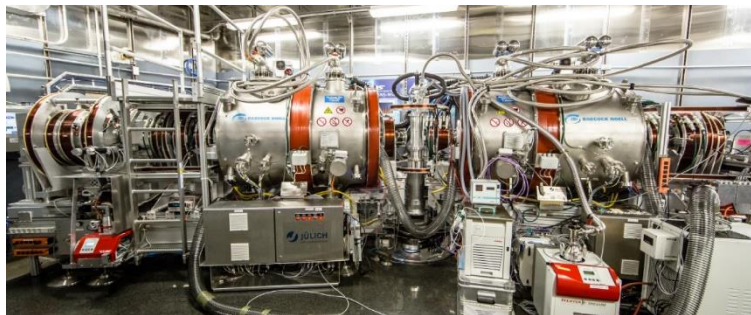
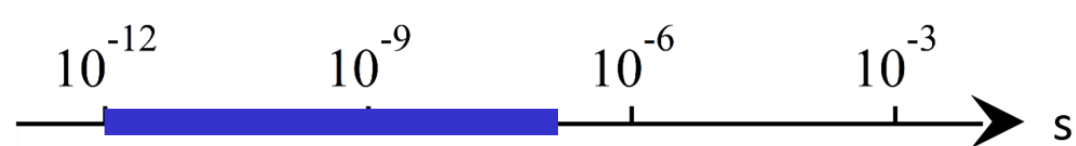
Le magnétisme à l'échelle mésoscopique: avec quels outils?



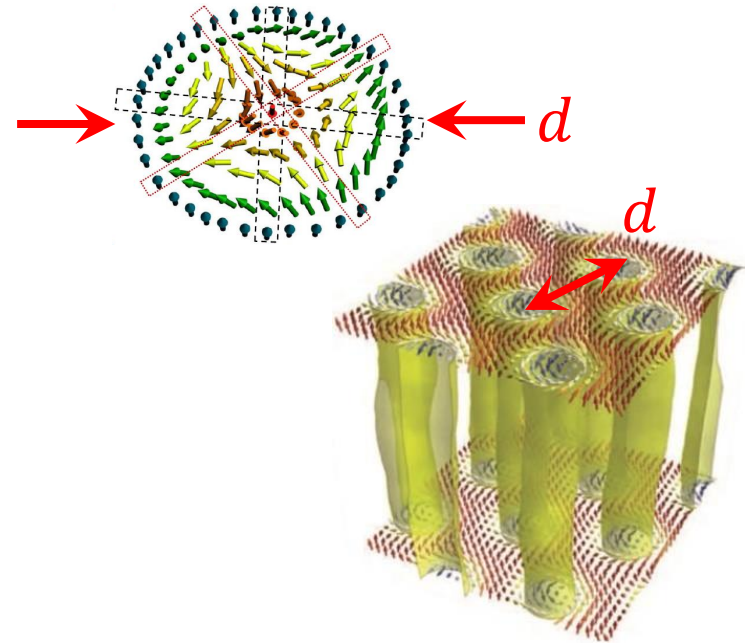
Diffraction de rayonnements aux petits angles (SANS/SAXS)



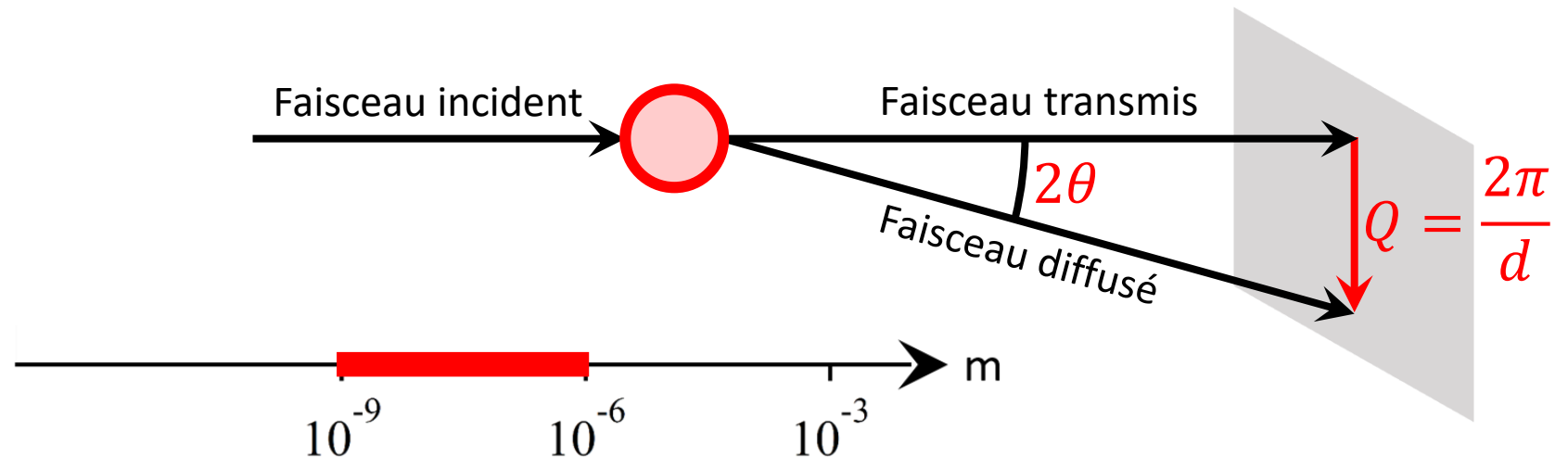
Spectroscopie neutronique (Q et ω)



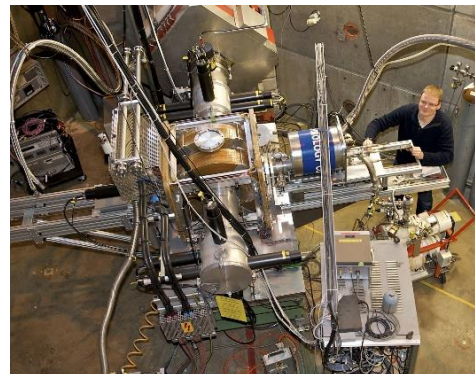
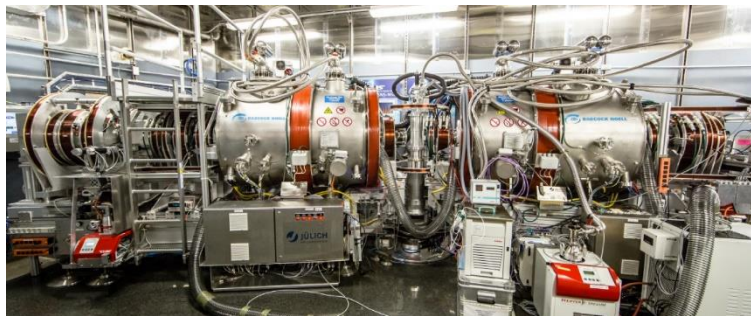
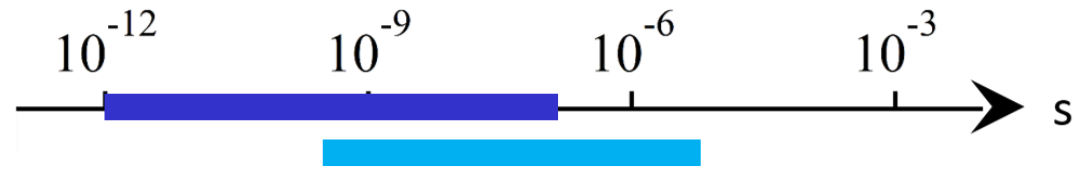
Le magnétisme à l'échelle mésoscopique: avec quels outils?



Diffraction de rayonnements aux petits angles (SANS/SAXS)

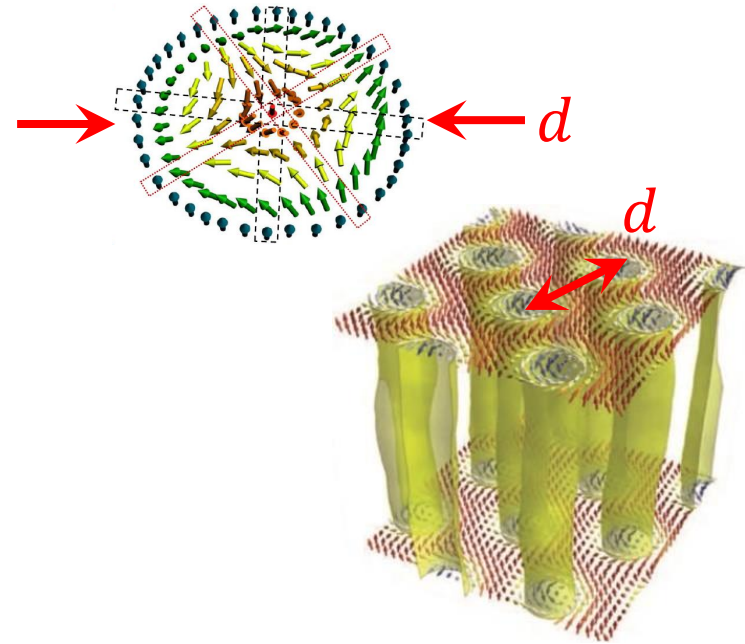


Spectroscopie neutronique (Q et ω)

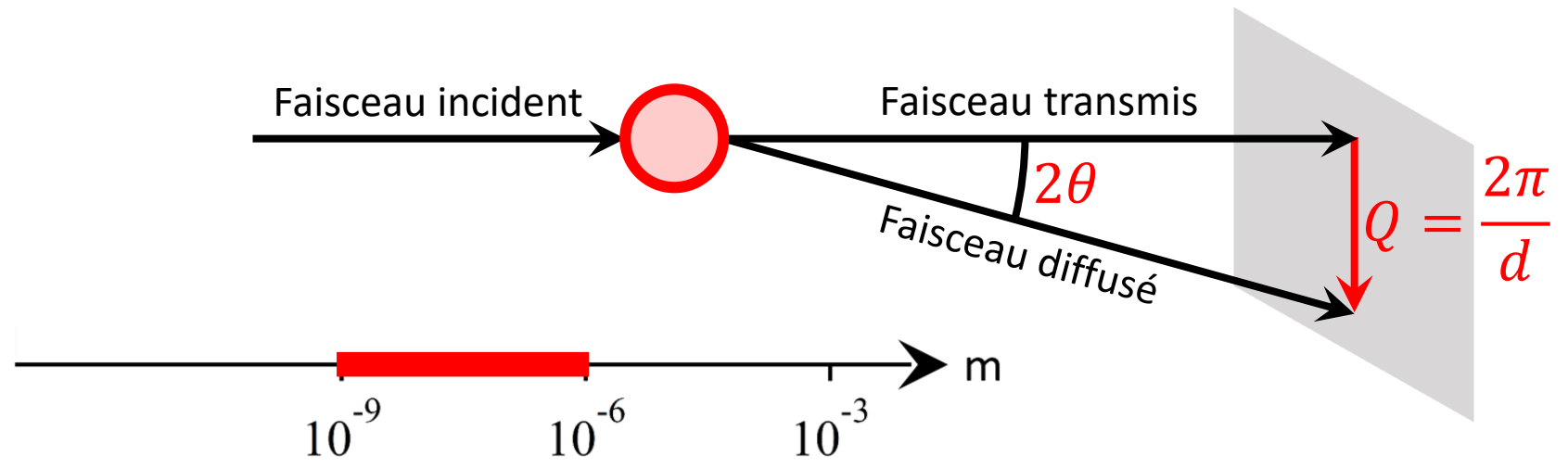


Rotation du spin du muon

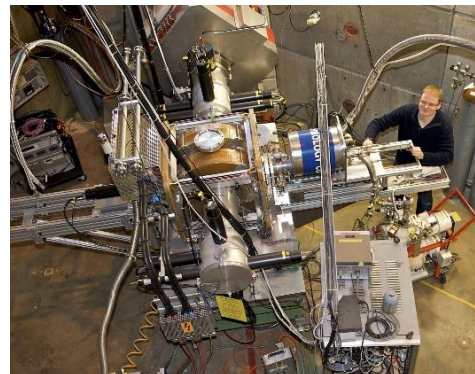
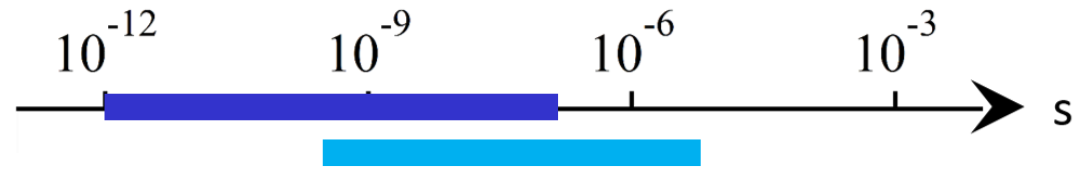
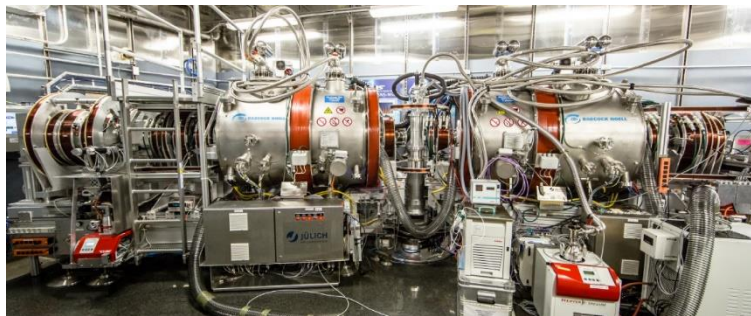
Le magnétisme à l'échelle mésoscopique: avec quels outils?



Diffraction de rayonnements aux petits angles (SANS/SAXS)



Spectroscopie neutronique (Q et ω)



Rotation du spin du muon

Magnétométrie



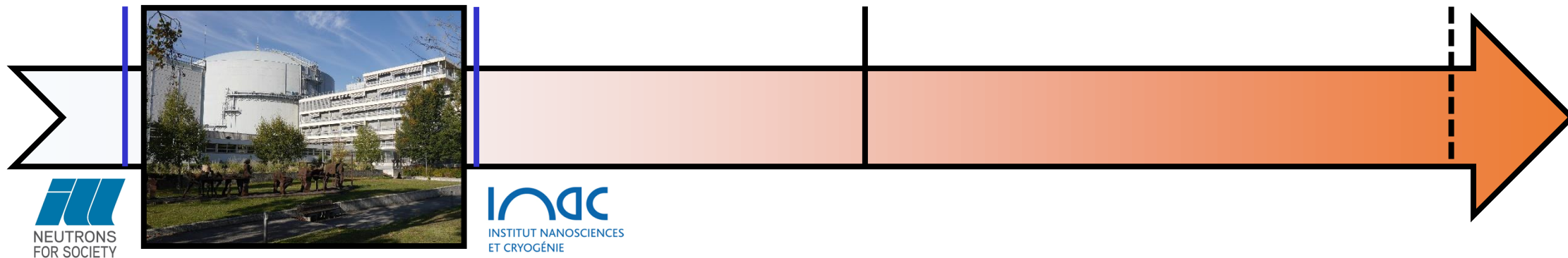
Mon parcours scientifique

2008

2012

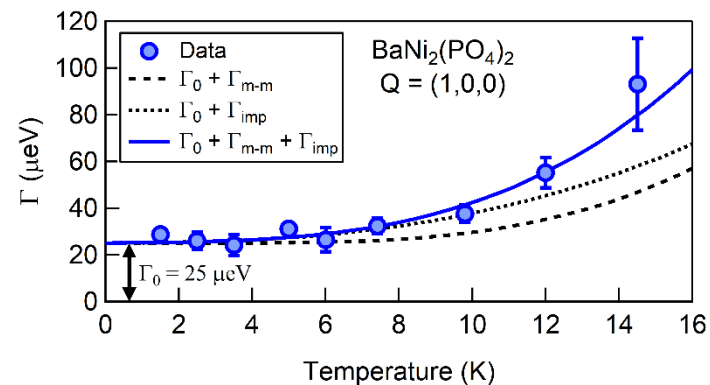
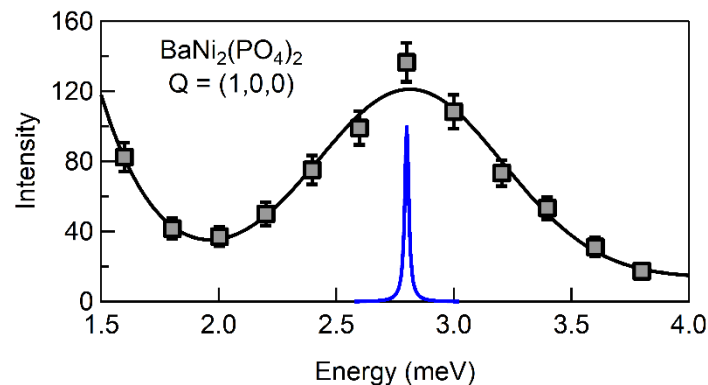
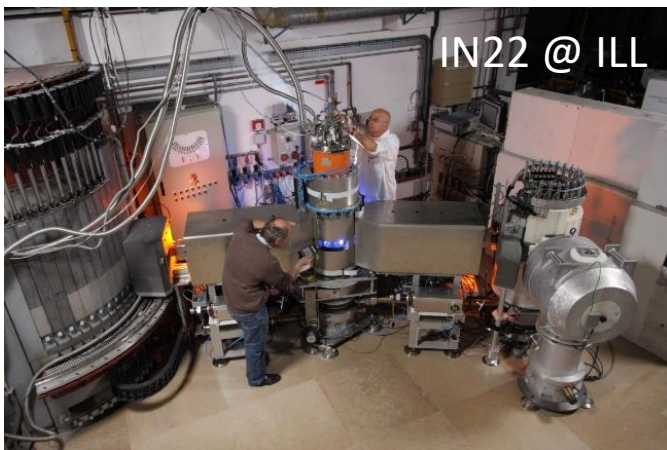
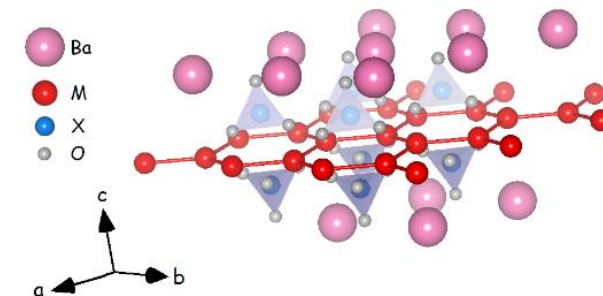
2014

2019



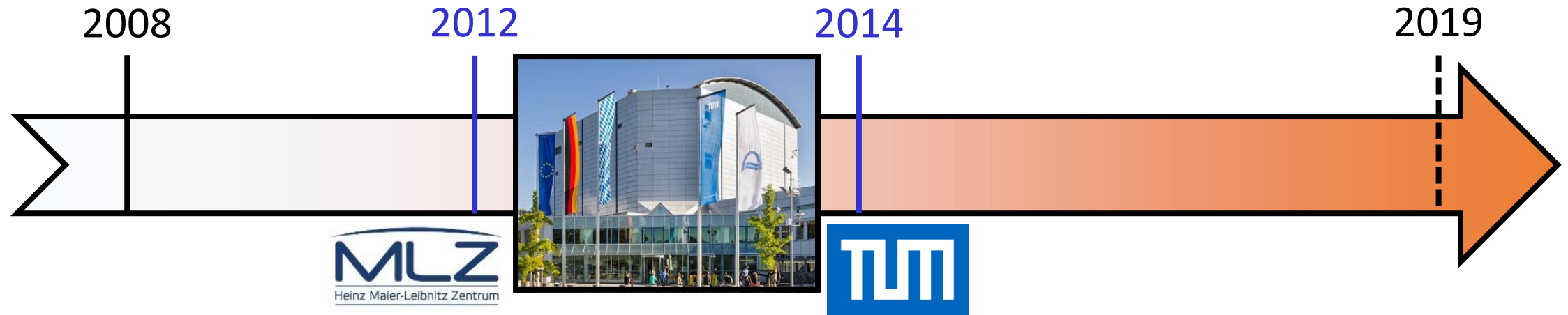
Thèse de doctorat (L.-P. Regnault)

- Systèmes magnétiques de basse dimension
- Spectroscopie à écho de spin neutronique résonant



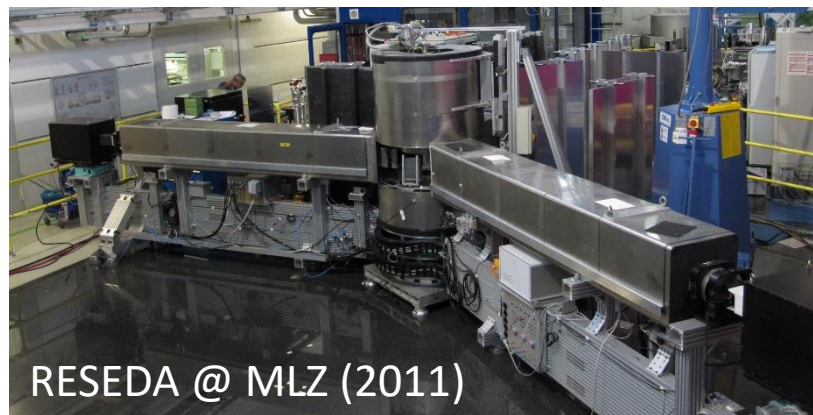
N. Martin (co-auteur), Phys. Rev. Lett. **109**, 097201 (2012)

Mon parcours scientifique



Postdoc #1: Co-responsable de l'instrument RESEDA

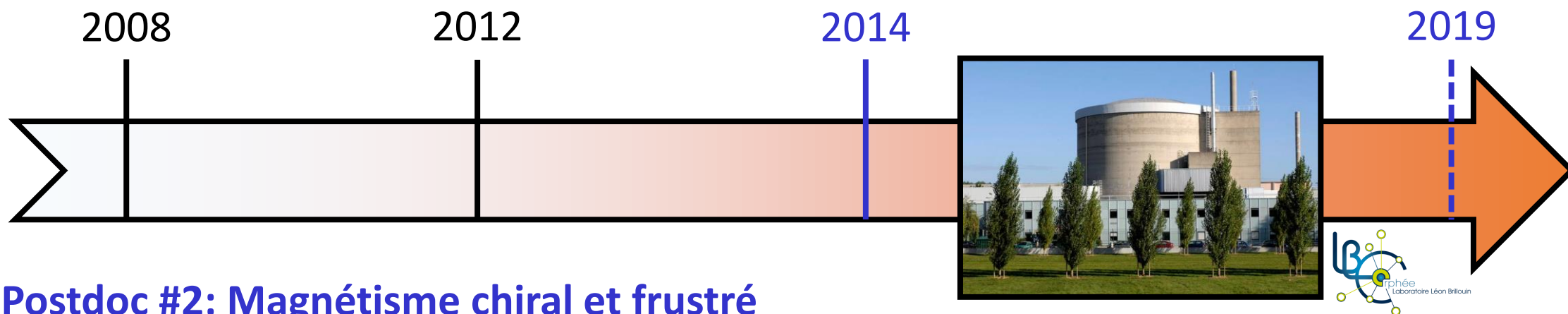
→ "MIEZE" – Etudes à haute résolution d'objets mésoscopiques en conditions extrêmes (H, P, T)



N. Martin et al., Rev. Sci. Instrum. **85**, 073902 (2014)

J. Kindervater, N. Martin et al., EPJ **83**, 03008 (2015)

Mon parcours scientifique



Postdoc #2: Magnétisme chiral et frustré (2014-2019)

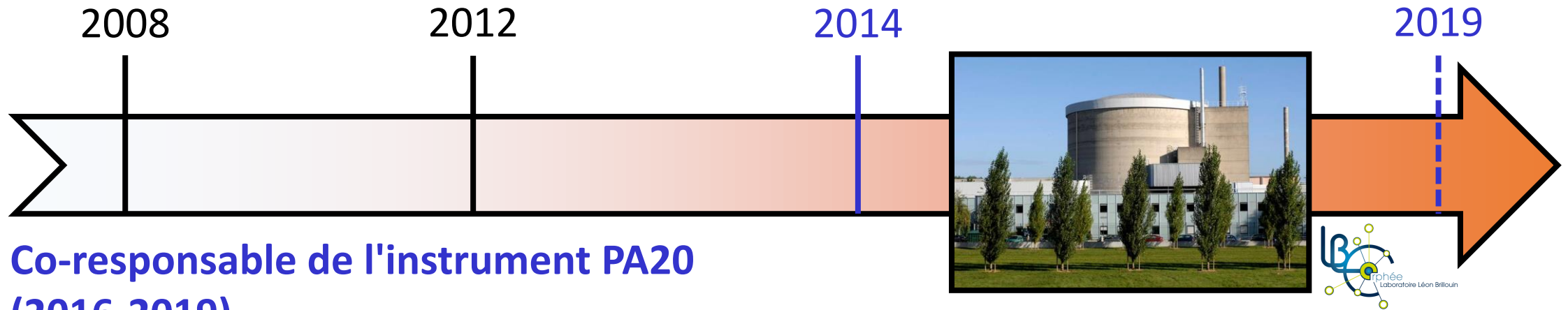
→ **Aimants chiraux cubiques, verres de spin réentrants et glaces de spin**

- ✓ Diffusion neutronique
- ✓ Spectroscopie (HAXPES et XMCD) + diffraction sous haute-pression en synchrotron
- ✓ Rotation du spin du muon (μ SR)



N. Martin et al., PRB **93**, 174405 (2016)
N. Martin et al., PRB **93**, 214404 (2016)
N. Martin et al., PRB Rapid Comm. **96**, 020413 (2017)
N. Martin et al., PRX **7**, 041028 (2017)
N. Martin (co-auteur), PRB **96**, 184416 (2017)
I. Mirebeau, N. Martin et al., PRB **98**, 014420 (2018)
N. Martin et al., PRB Rapid Comm. **99**, 100402 (2019)

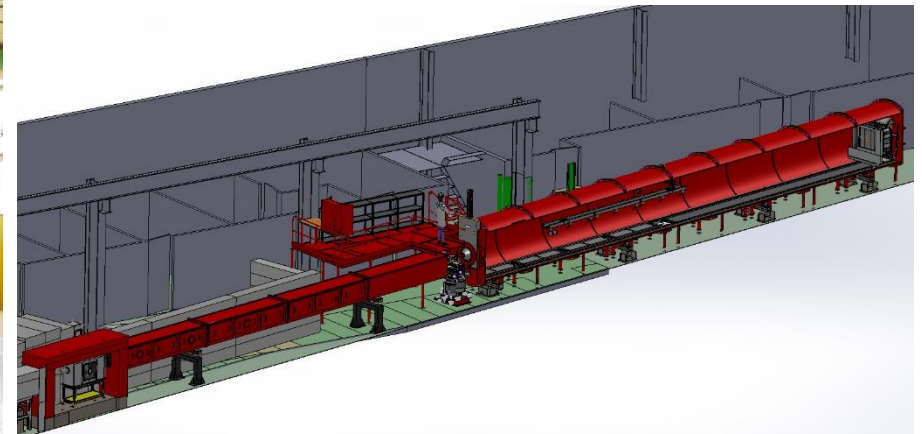
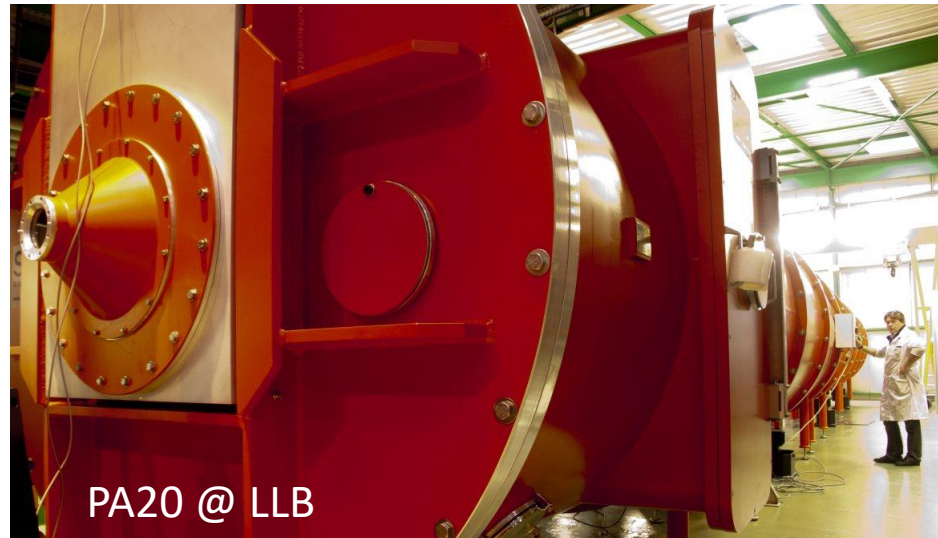
Mon parcours scientifique



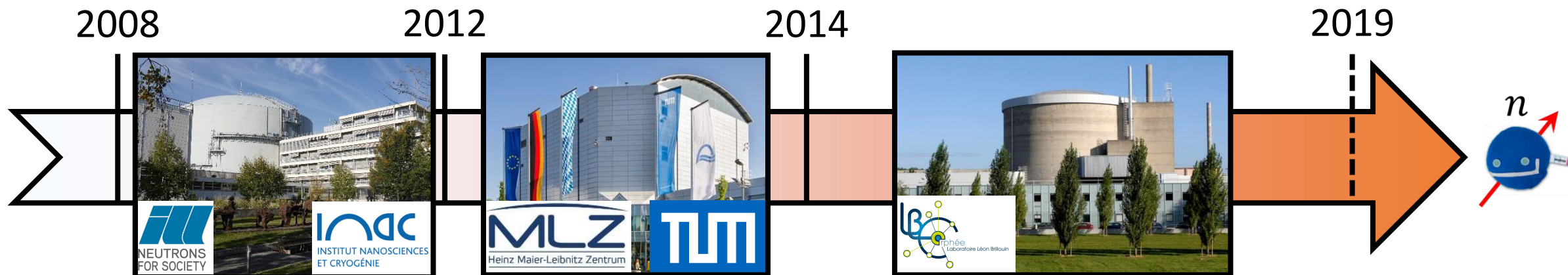
Co-responsable de l'instrument PA20 (2016-2019)

→ Développement des activités expérimentales en matière 'dure' et magnétisme

N. Martin et al., PRB **93**, 174405 (2016)
N. Martin et al., PRB **93**, 214404 (2016)
N. Martin et al., PRB Rapid Comm. **96**, 020413 (2017)
N. Martin et al., PRX **7**, 041028 (2017)
N. Martin (co-auteur), PRB **96**, 184416 (2017)
I. Mirebeau, N. Martin et al., PRB **98**, 014420 (2018)
N. Martin et al., PRB Rapid Comm. **99**, 100402 (2019)



Mon parcours scientifique



Physicien expérimentateur

Propriétés magnétiques de la matière condensée

Liens structure ↔ dynamique

- Diffusion et spectroscopies de faisceaux quantiques (neutrons, rayons X et muons) en très grandes infrastructures de recherche
- Modélisation et développement instrumental



Programme de recherche

Fil conducteur

Ecart à l'ordre "conventionnel"



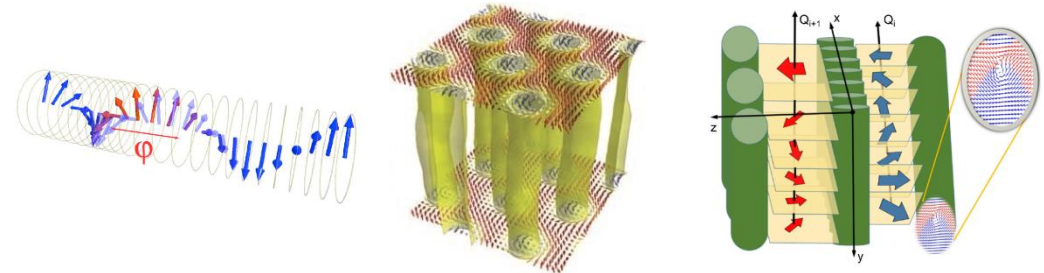
Textures magnétiques stables

Approche expérimentale

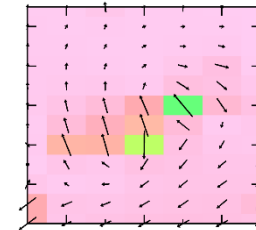
- ✓ Utilisation couplées de différentes sondes (neutrons, X et muons)
- ✓ Echantillons massifs → conditions extrêmes (H, P, T)

Objets d'étude

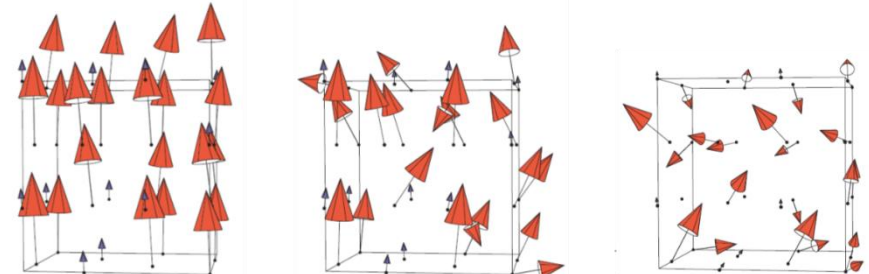
Thème 1: Solitons, skyrmions et phases torsadées



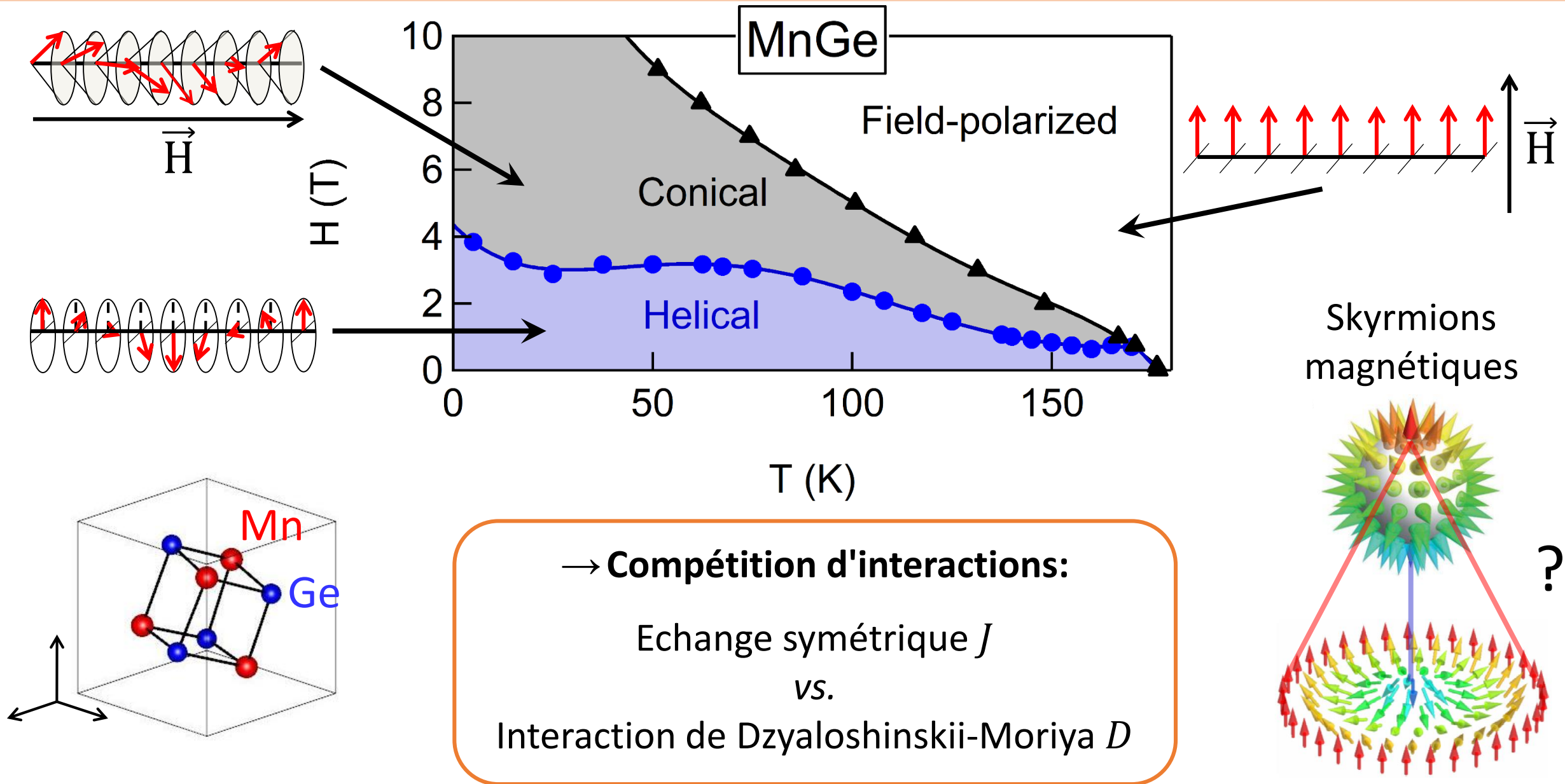
Thème 2: Vortex induits par frustration



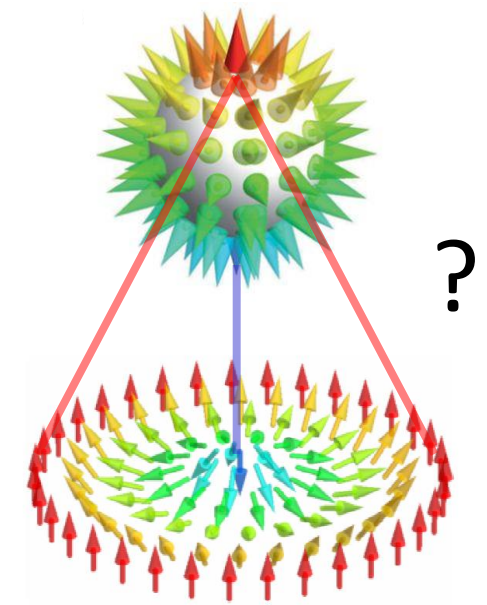
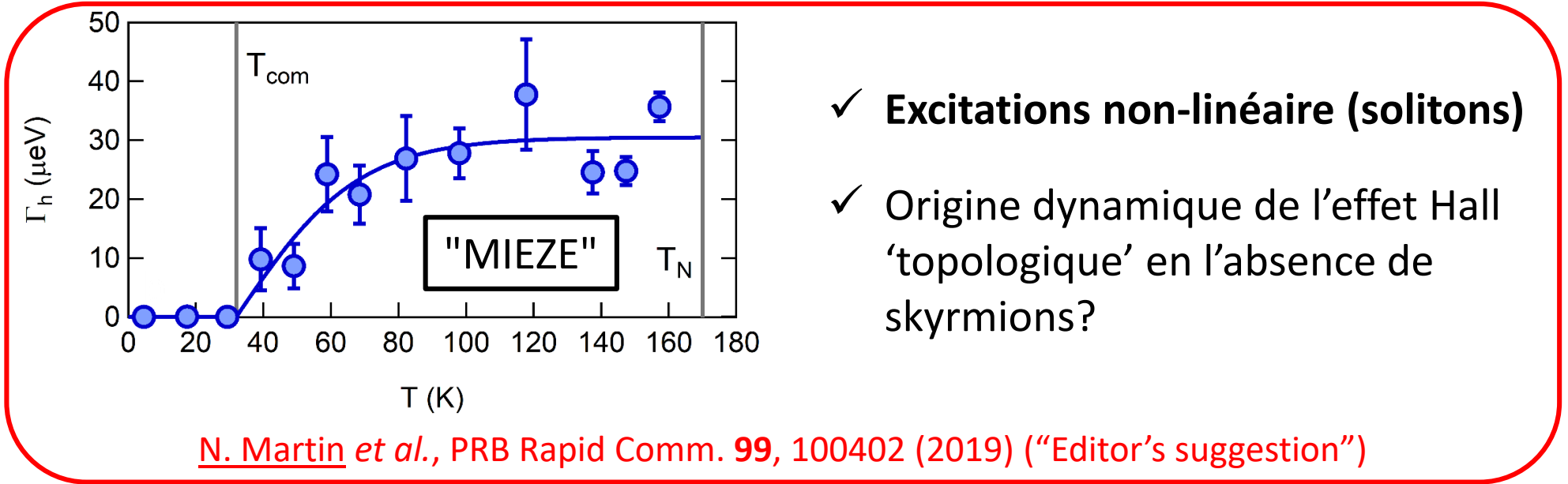
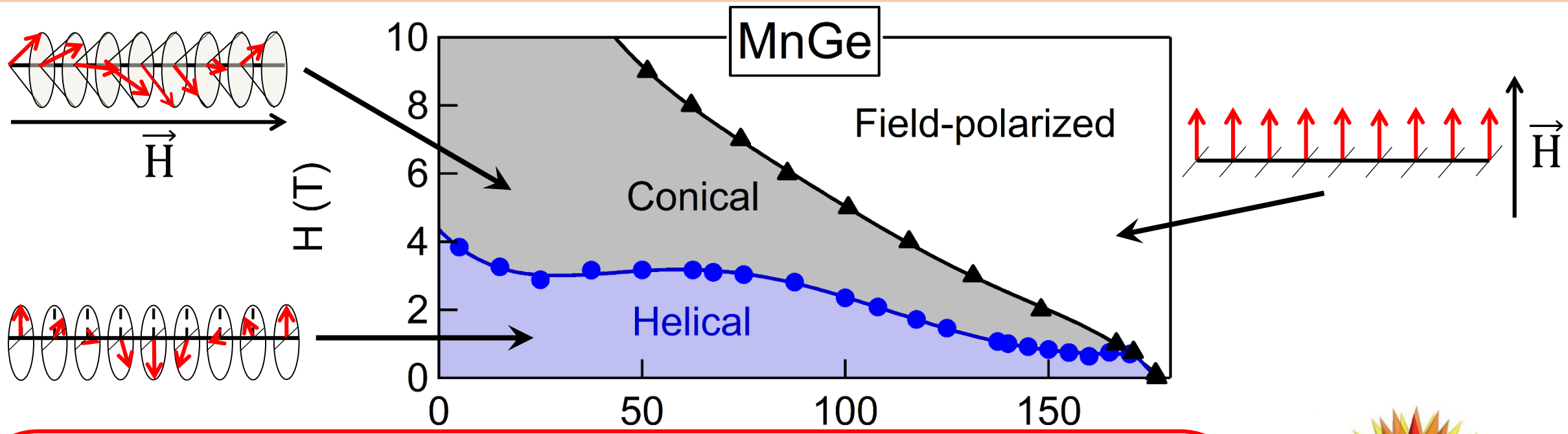
Thème 3: Textures magnétiques et effet 'Invar'



Thème 1: Solitons, skyrmions et phases torsadées



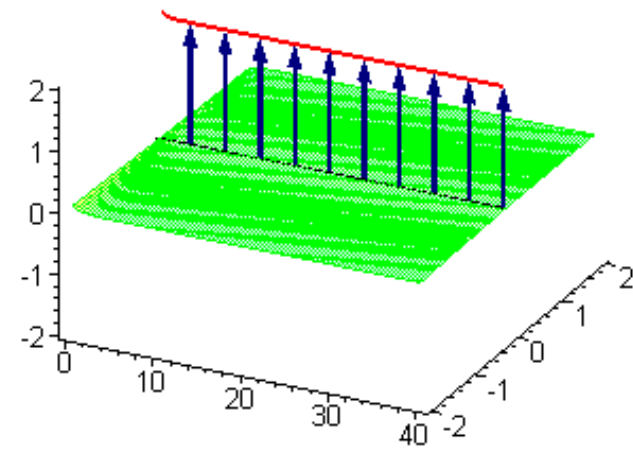
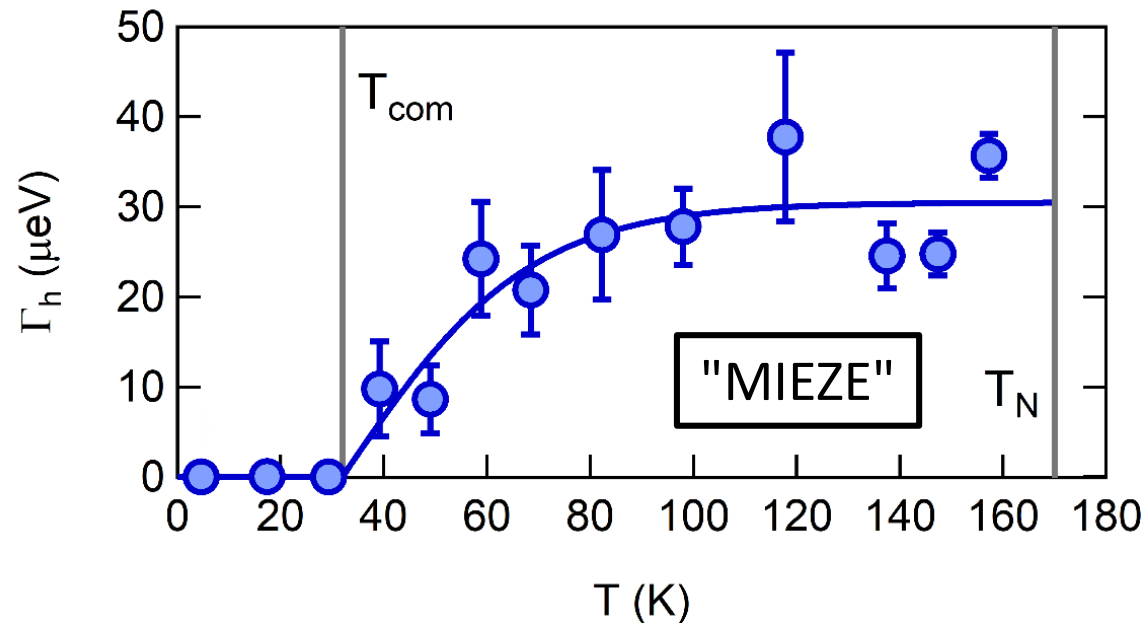
Thème 1: Solitons, skyrmions et phases torsadées



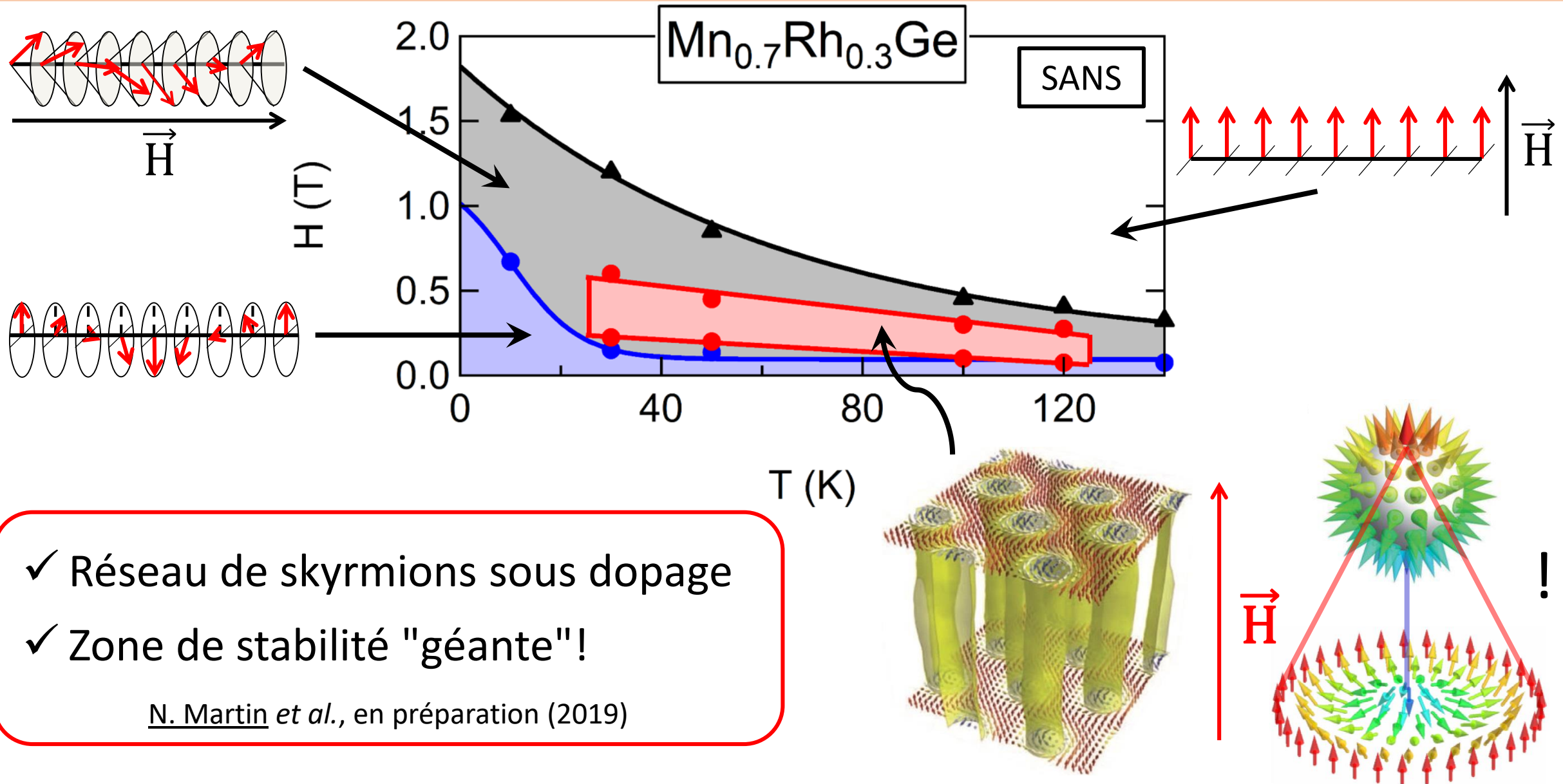
Thème 1: Solitons, skyrmions et phases torsadées

- Evolution du spectre de fluctuations
- Contrôle du régime de propagation des solitons (dopage)
- Effet du champ magnétique

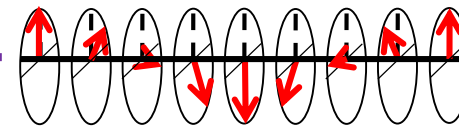
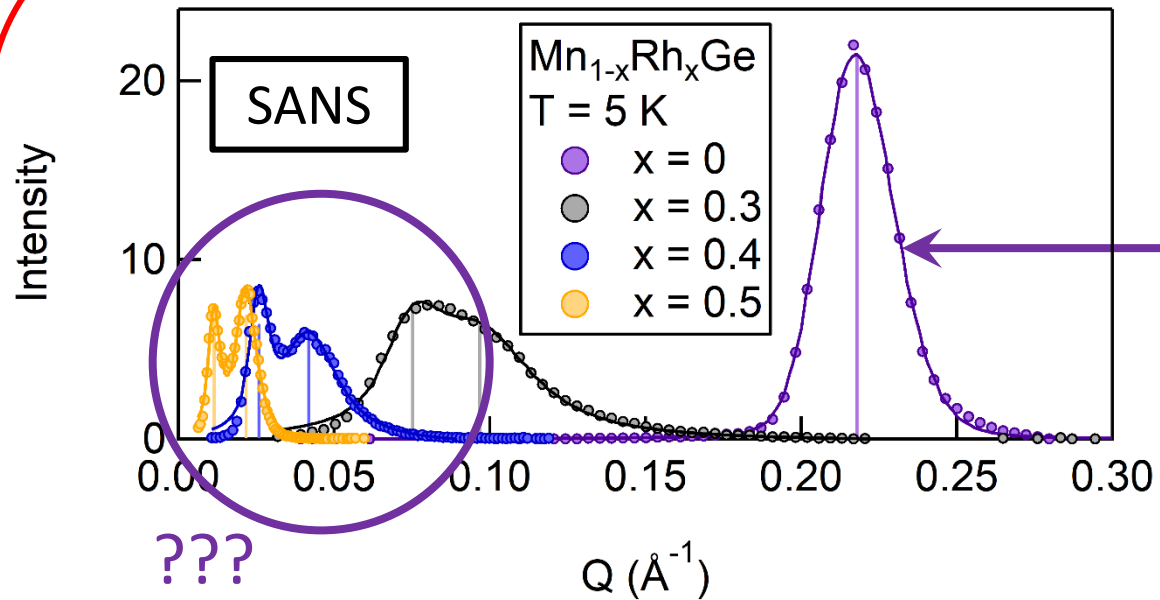
Moyen terme



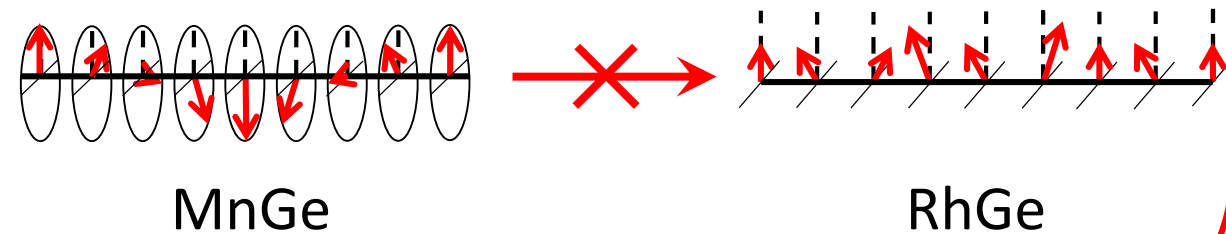
Thème 1: Solitons, skyrmions et phases torsadées



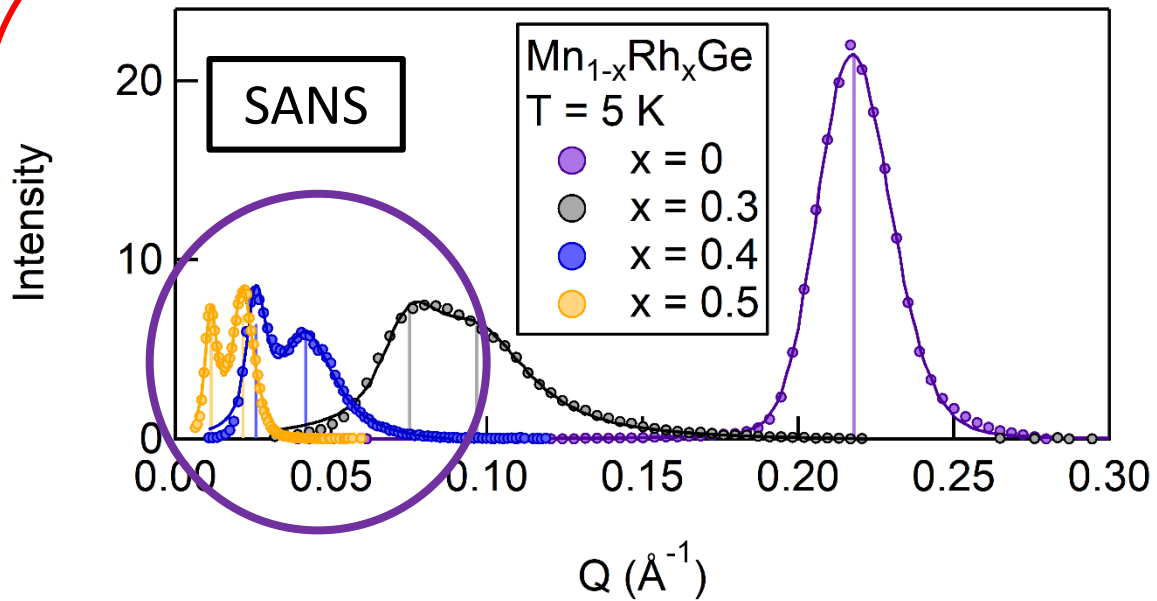
Thème 1: Solitons, skyrmions et phases torsadées



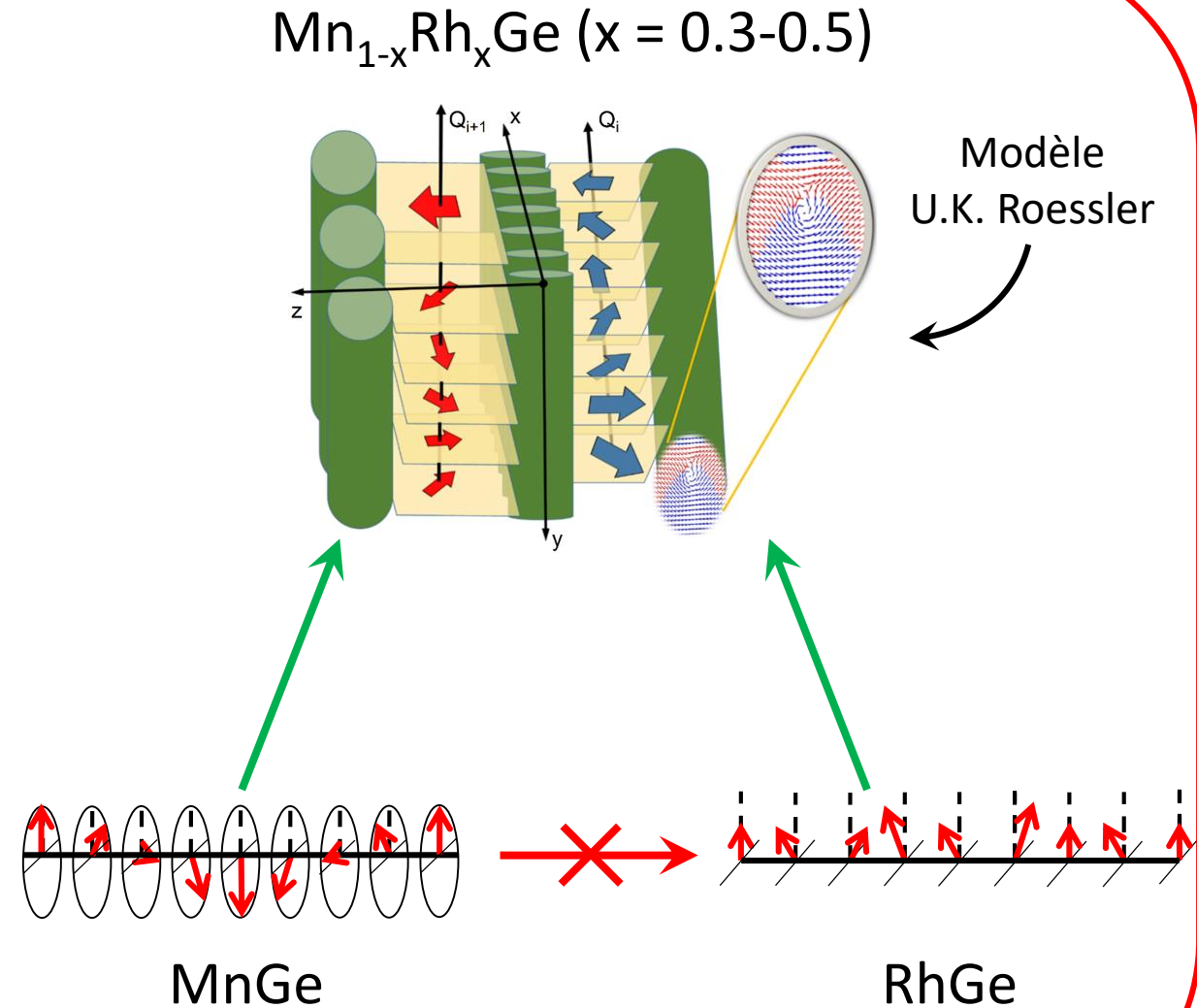
- ✓ Nouvelle périodicité dans le système
- ✓ Evolution discontinue vers RhGe (ferro. faible supraconducteur)



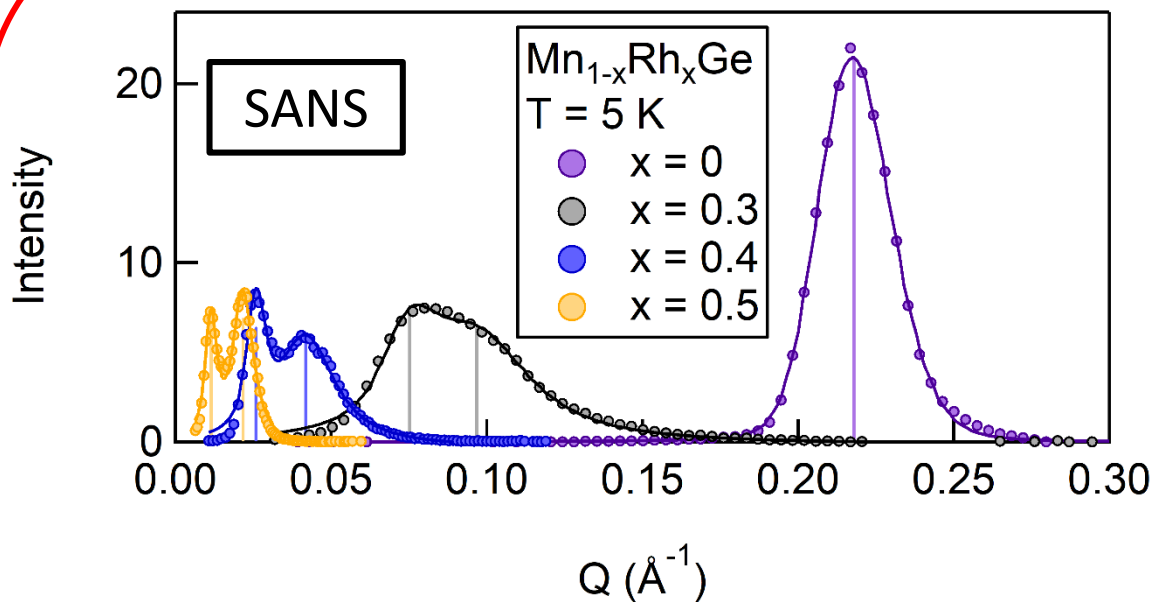
Thème 1: Solitons, skyrmions et phases torsadées



- ✓ Nouvelle périodicité dans le système
- ✓ Evolution discontinue vers RhGe (ferro. faible supraconducteur)

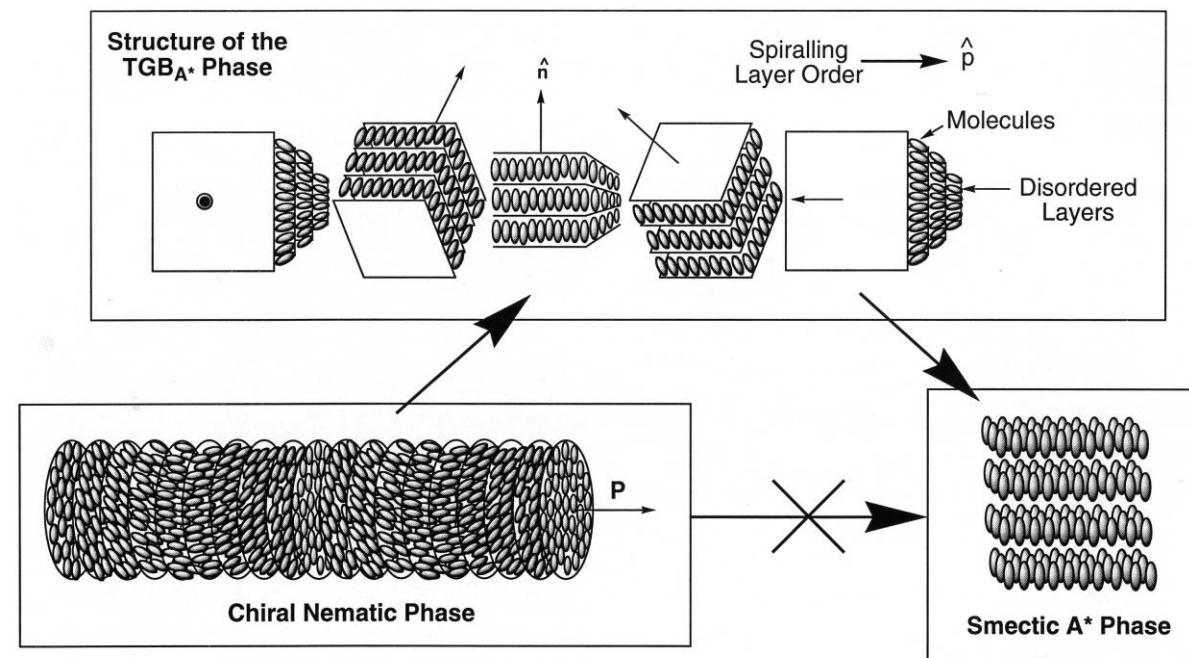


Thème 1: Solitons, skyrmions et phases torsadées



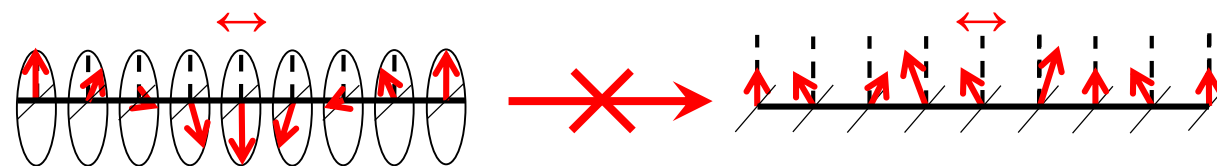
- ✓ Nouvelle périodicité dans le système
- ✓ Evolution discontinue vers RhGe (ferro. faible supraconducteur)

Phase à joint de grains torsadés (TGB)



Cholestérique

Smectique



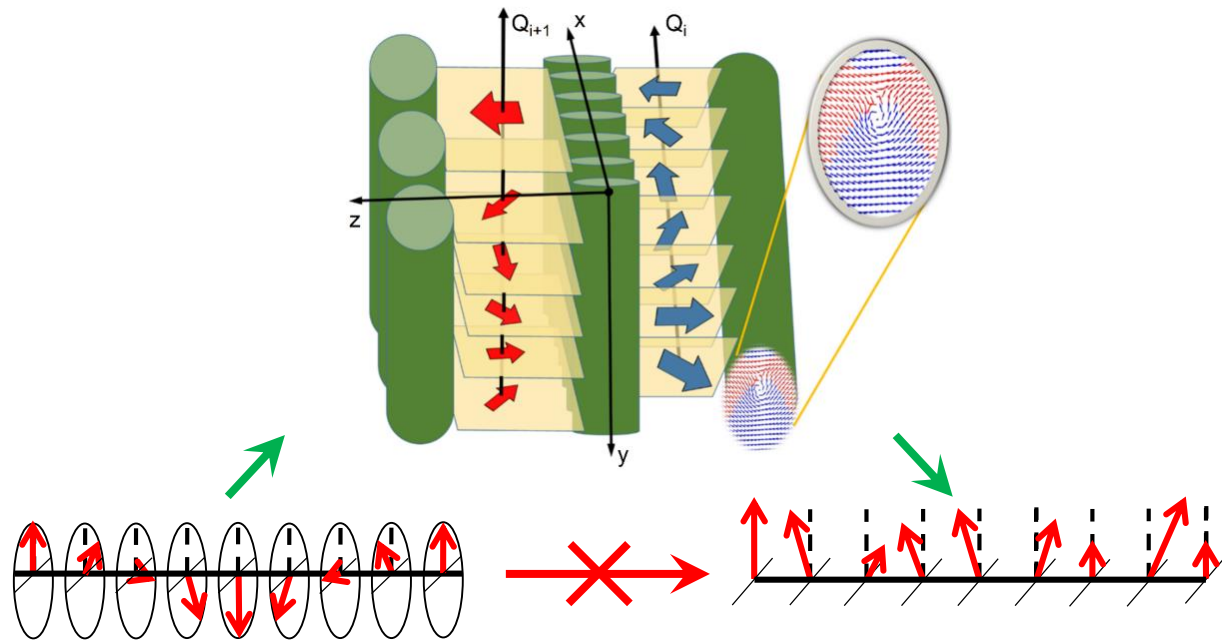
Thème 1: Solitons, skyrmions et phases torsadées

PROJET

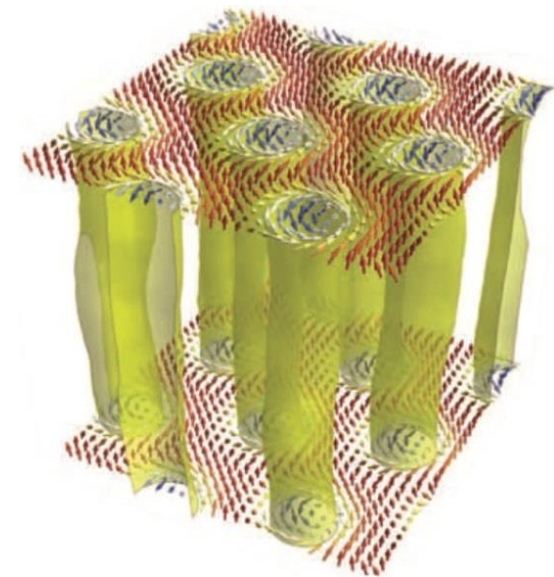
- Organisation spatiale et criticalité des phases TGB
- Nature du réseau de skyrmions
- Test de l'universalité des phases TGB

Court terme

Moyen terme

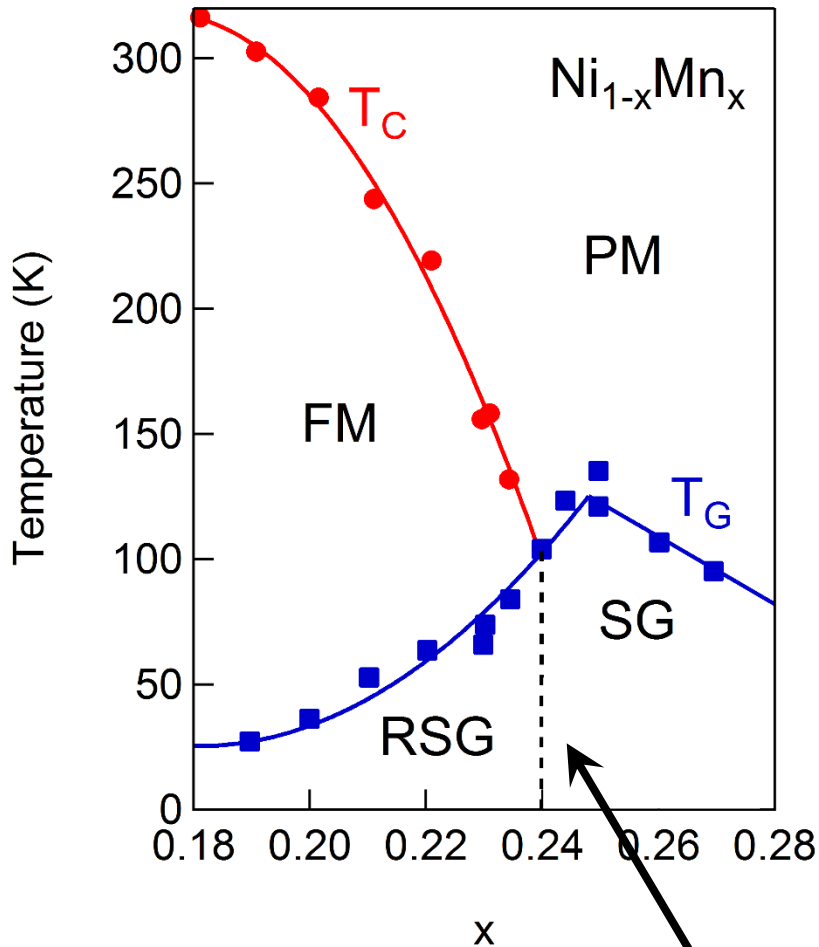


Phases torsadées ("TGB magnétiques")



Réseau de skyrmions

Thème 2: Vortex induits par frustration



→ Frustration d'échange entre ions premiers voisins:

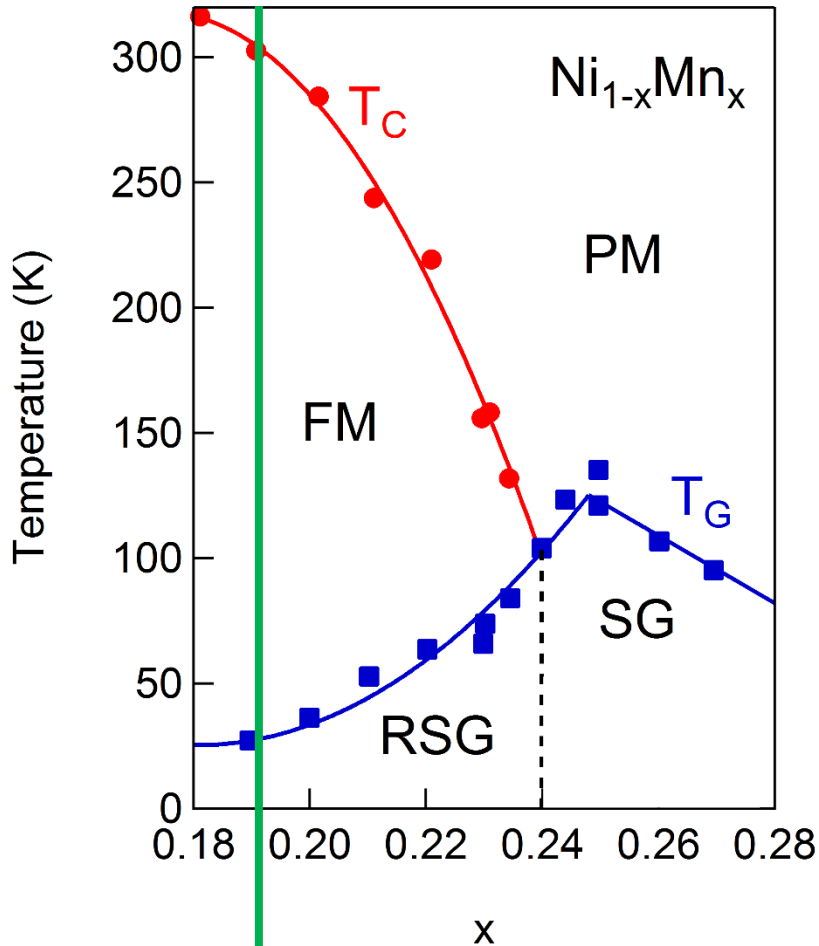
- ✓ Ni-Ni & Ni-Mn: matrice ferromagnétique ↑↑
- ✓ Mn-Mn: impuretés antiferromagnétiques ↑↓

Verre de spin

Thème 2: Vortex induits par frustration

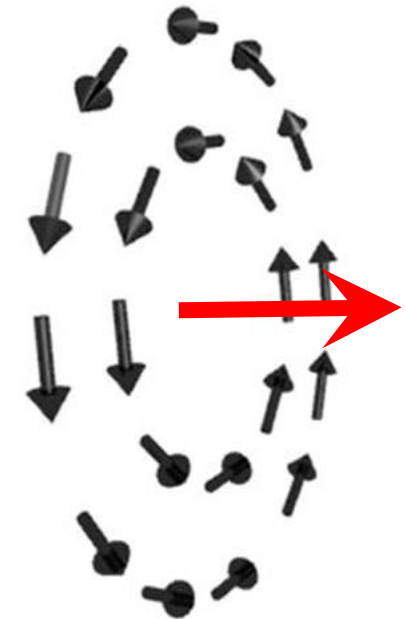
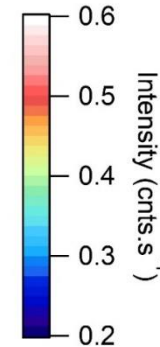
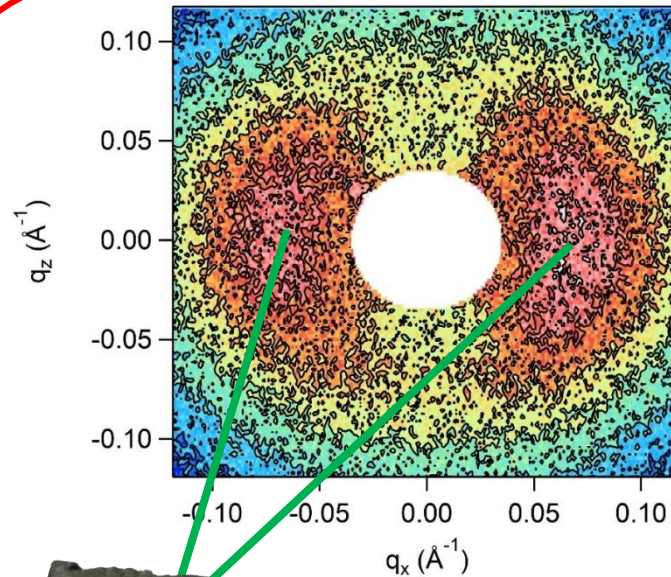
→ Frustration d'échange entre ions premiers voisins:

- ✓ Ni-Ni & Ni-Mn: matrice ferromagnétique $\uparrow\uparrow$
- ✓ Mn-Mn: impuretés antiferromagnétiques $\uparrow\downarrow$



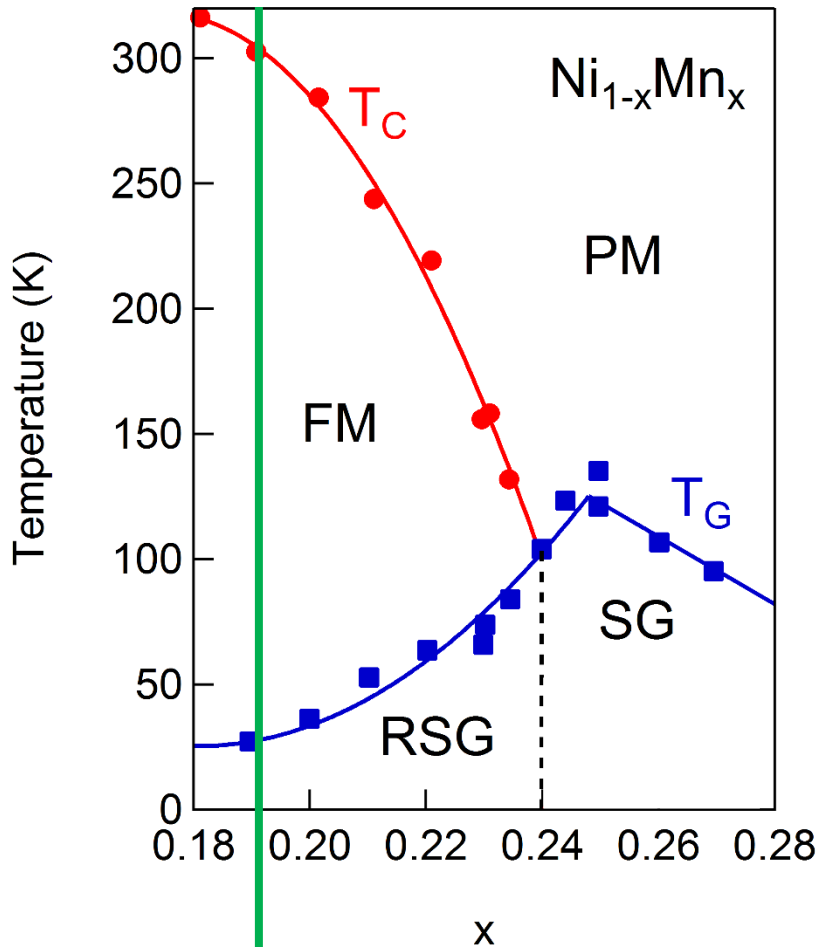
$x = 0.19$

Diagramme de phase adapté de
R.L. Sommer *et al.*, JMMM **103** (1992) 25



I. Mirebeau, N. Martin *et al.*, Physical Review B **98**, 014420 (2018)

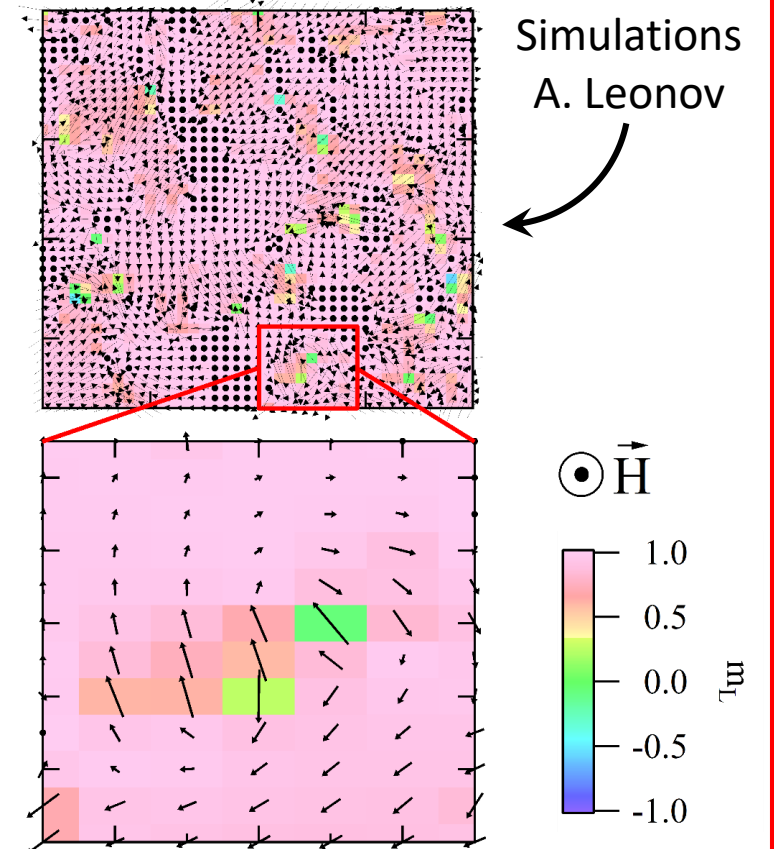
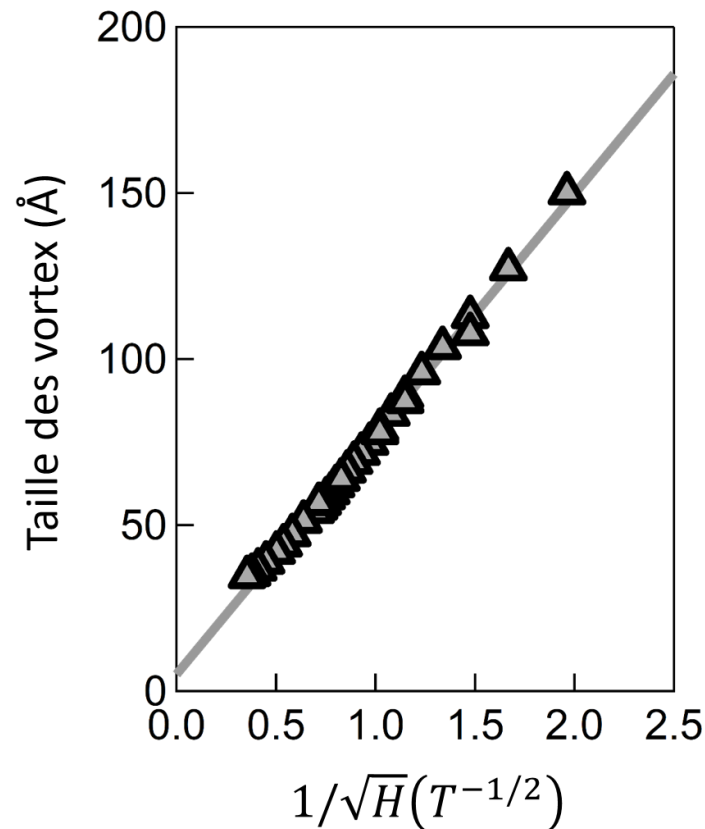
Thème 2: Vortex induits par frustration



$x = 0.19$

Diagramme de phase adapté de
R.L. Sommer *et al.*, JMMM **103** (1992) 25

- ✓ Défauts robustes ($H_C \gg 10$ T)
- ✓ Contrôle "direct" de la taille et de la densité des vortex



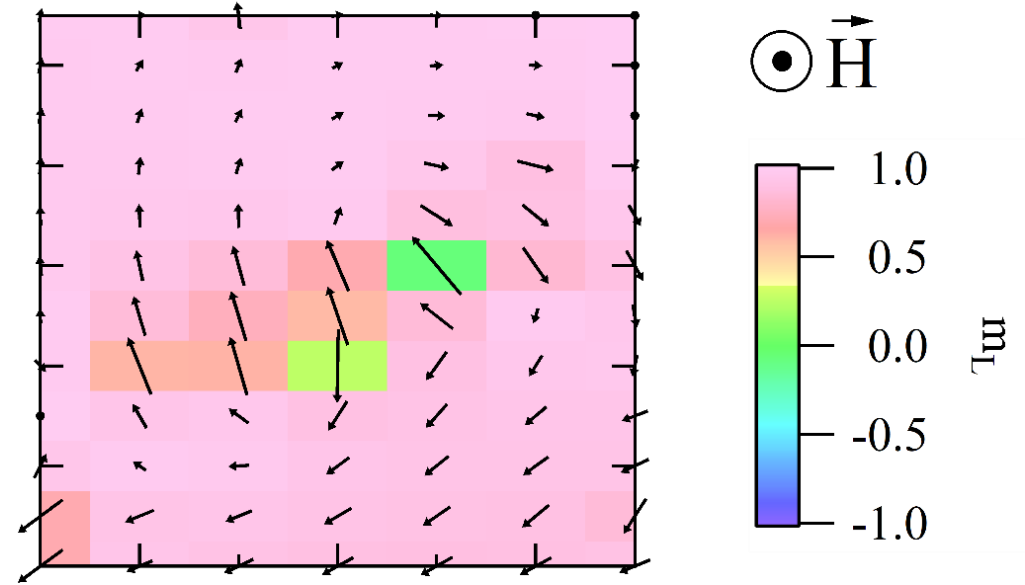
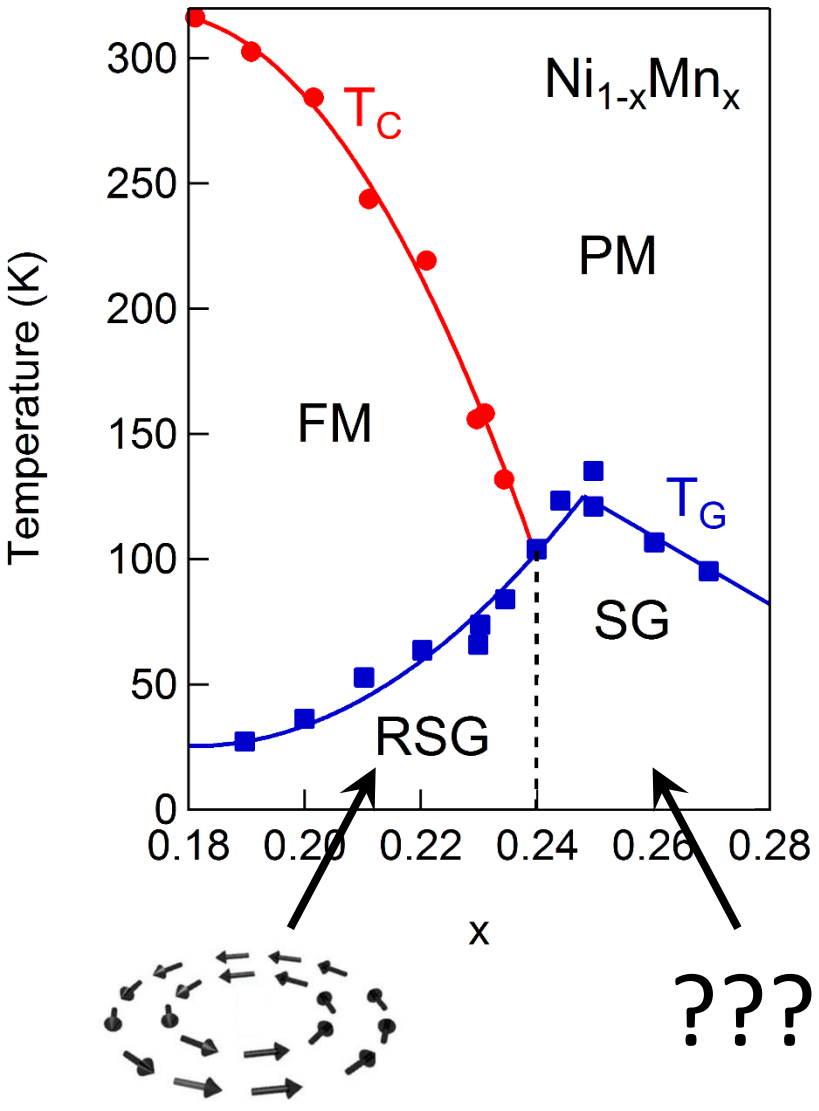
I. Mirebeau, N. Martin *et al.*, Physical Review B **98**, 014420 (2018)

Thème 2: Vortex induits par frustration

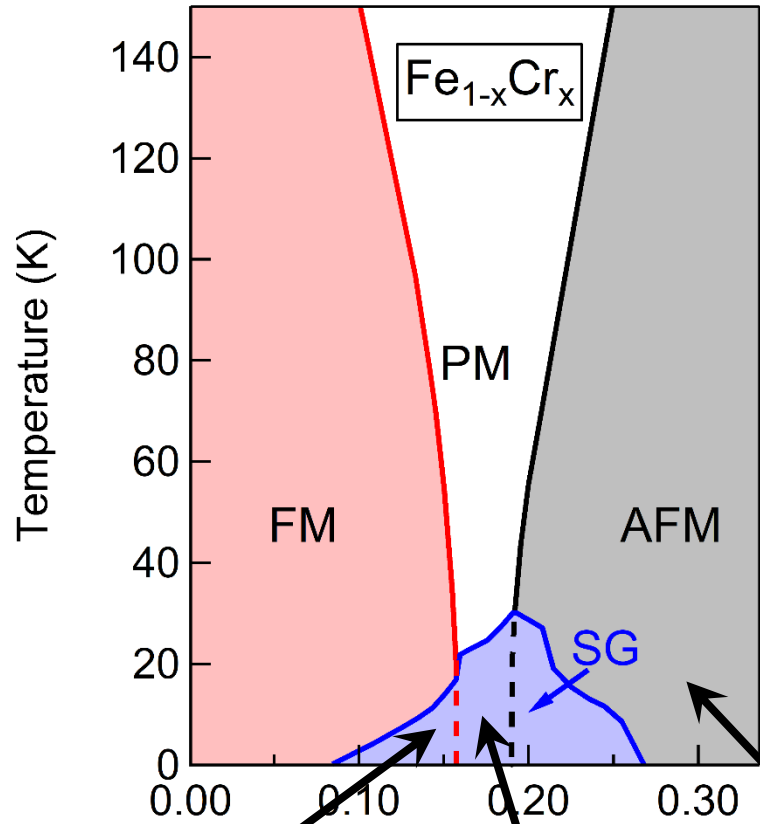
PROJET

- Criticalité en fonction du dopage
 - Vortex en environnement AFM
 - Dynamique des vortex
- Court terme

Moyen terme

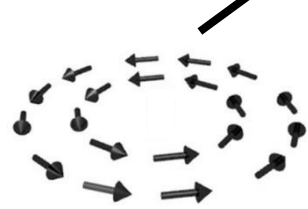


Thème 2: Vortex induits par frustration

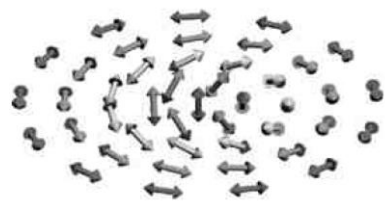


- Criticalité en fonction du dopage
 - Vortex en environnement AFM
 - Dynamique des vortex
- Court terme
- Moyen terme

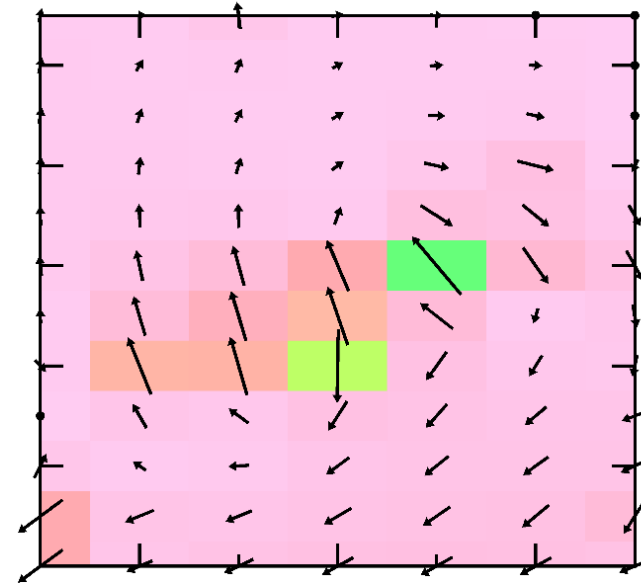
PROJET



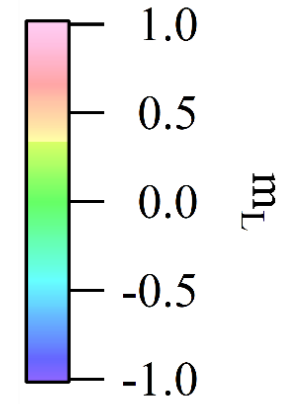
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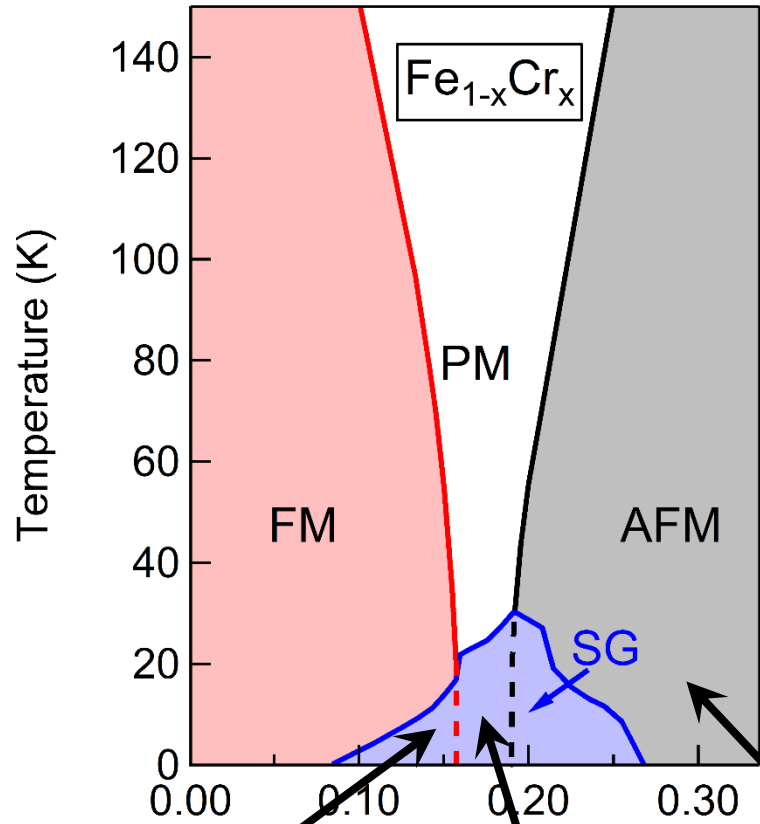


$\odot \vec{H}$



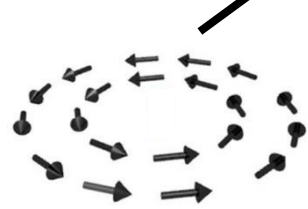
m_z

Thème 2: Vortex induits par frustration

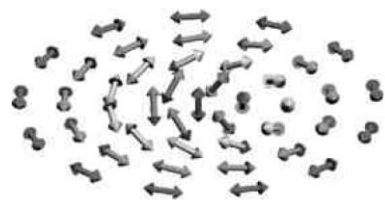


- Criticalité en fonction du dopage
 - Vortex en environnement AFM
 - Dynamique des vortex
- Court terme
- Moyen terme

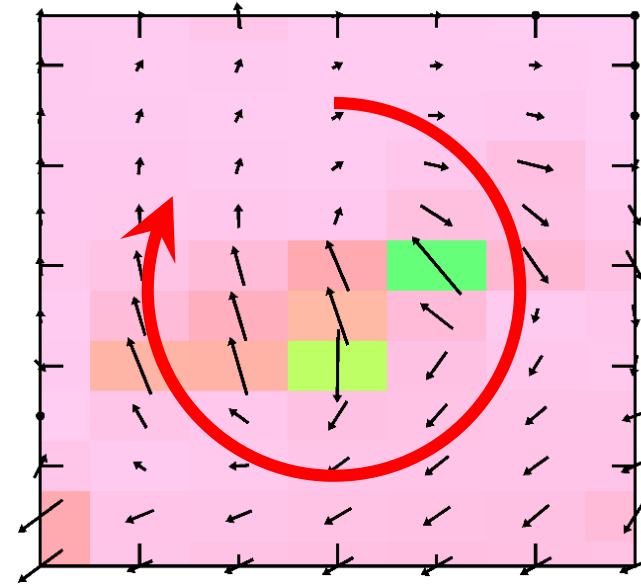
PROJET



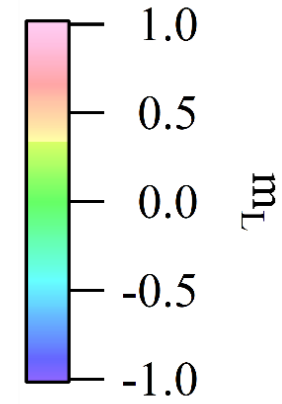
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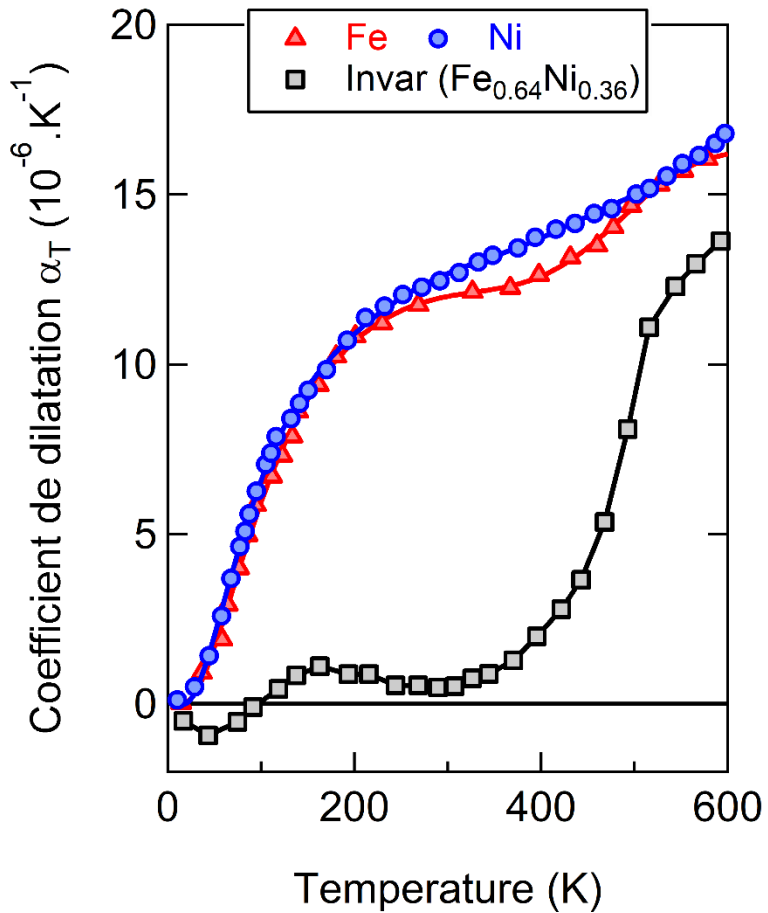
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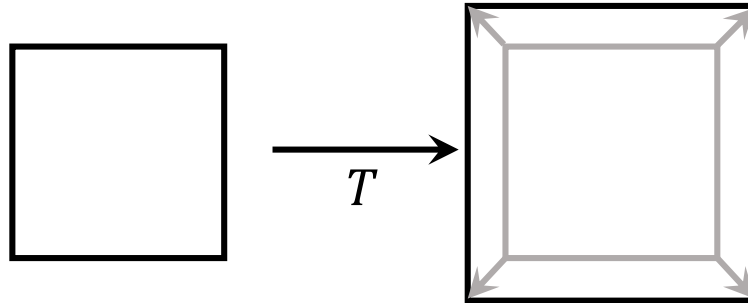
$\odot \vec{H}$



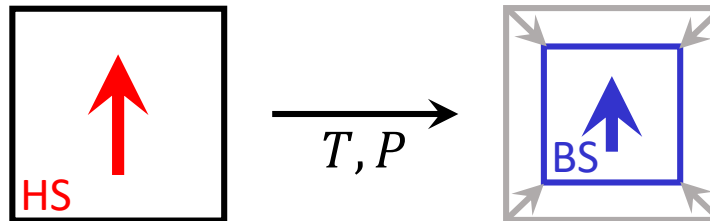
Thème 3: Textures magnétiques et effet 'Invar'



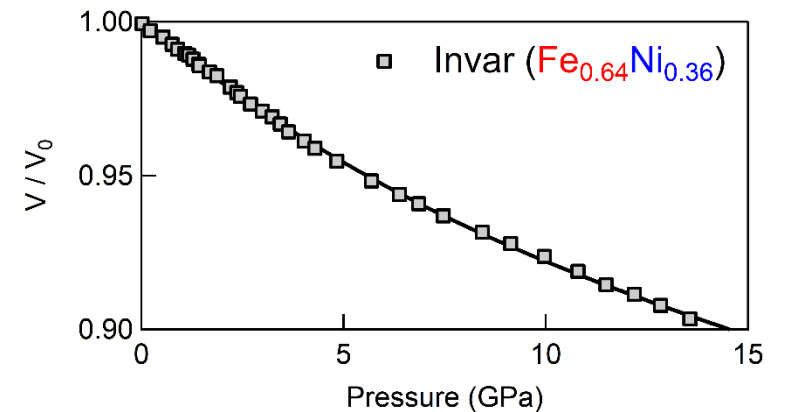
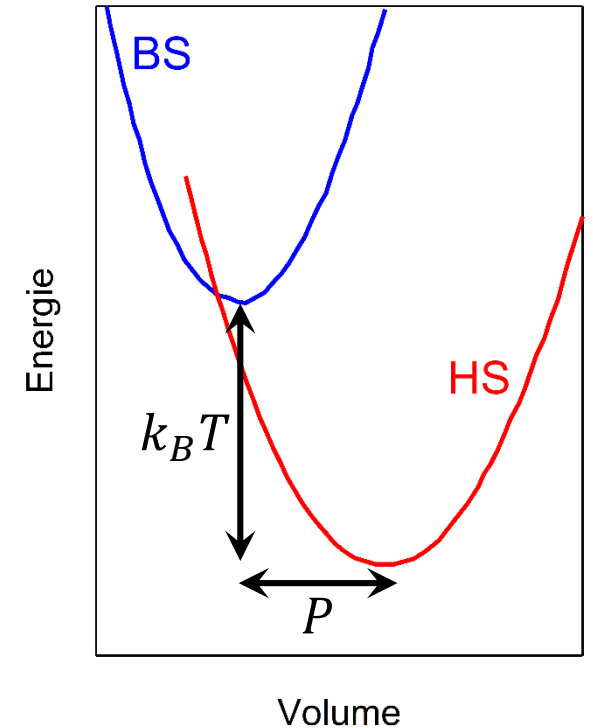
- Expansion thermique:



+ Transition Haut Spin-Bas Spin?

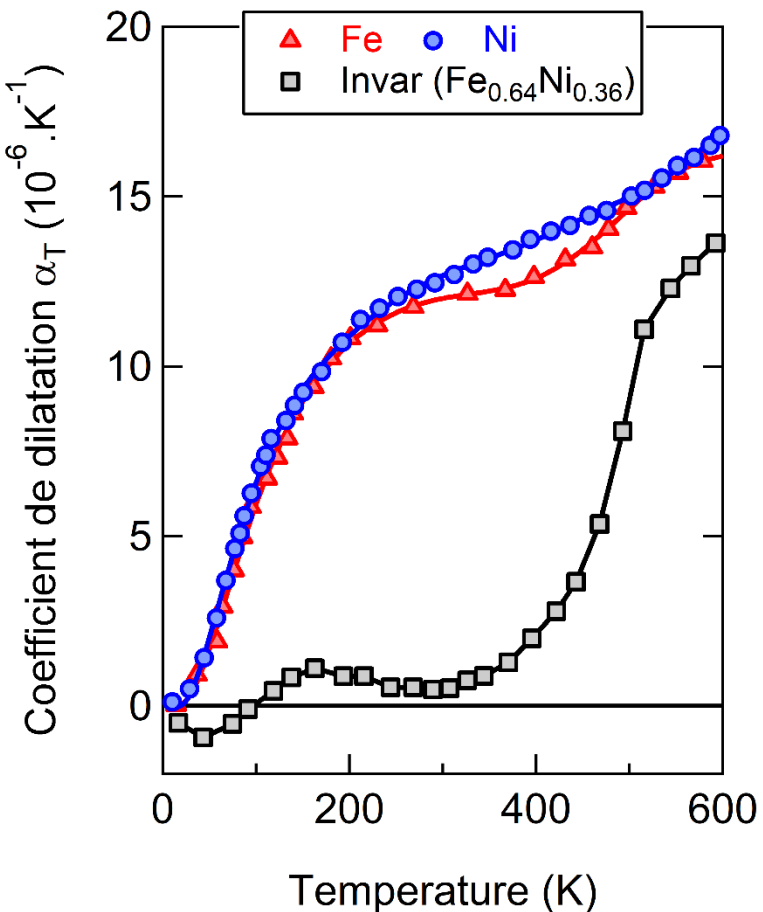


R.J. Weiss, Proc. Phys. Soc. **82**, 281 (1963)

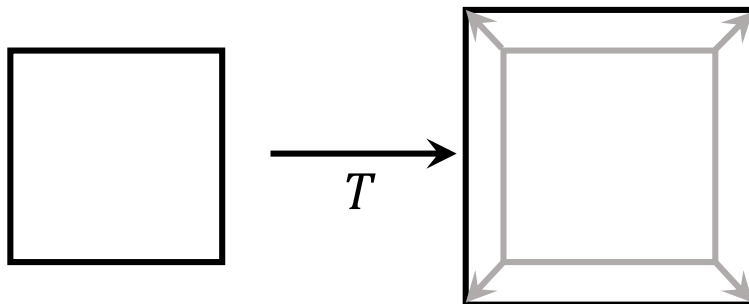


L. Nataf *et al.*, Phys. Rev. B **74**, 184422 (2006)

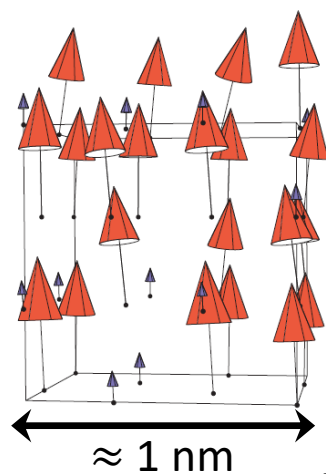
Thème 3: Textures magnétiques et effet 'Invar'



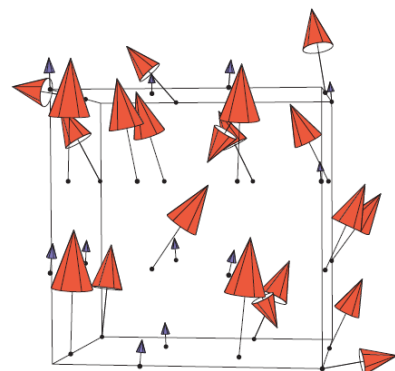
- Expansion thermique:



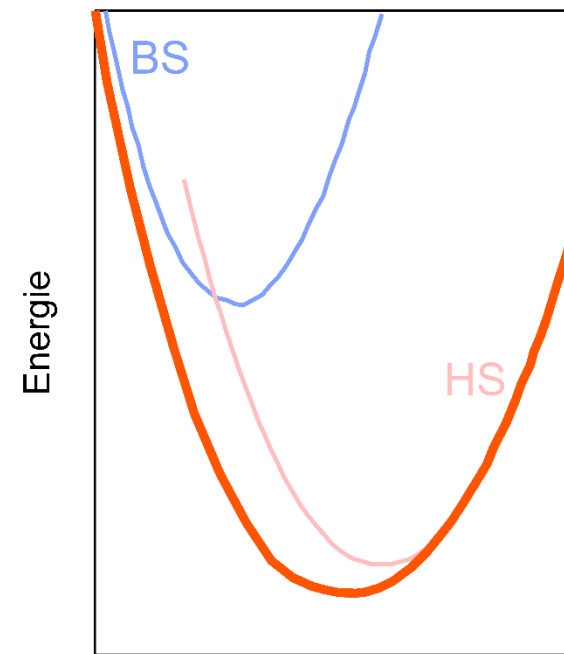
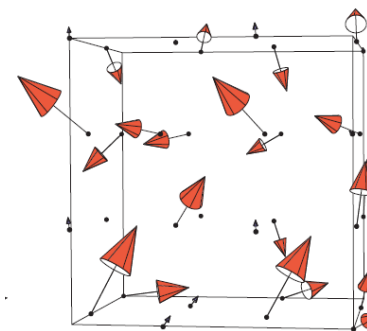
+ Distribution d'états non-collinéaires?



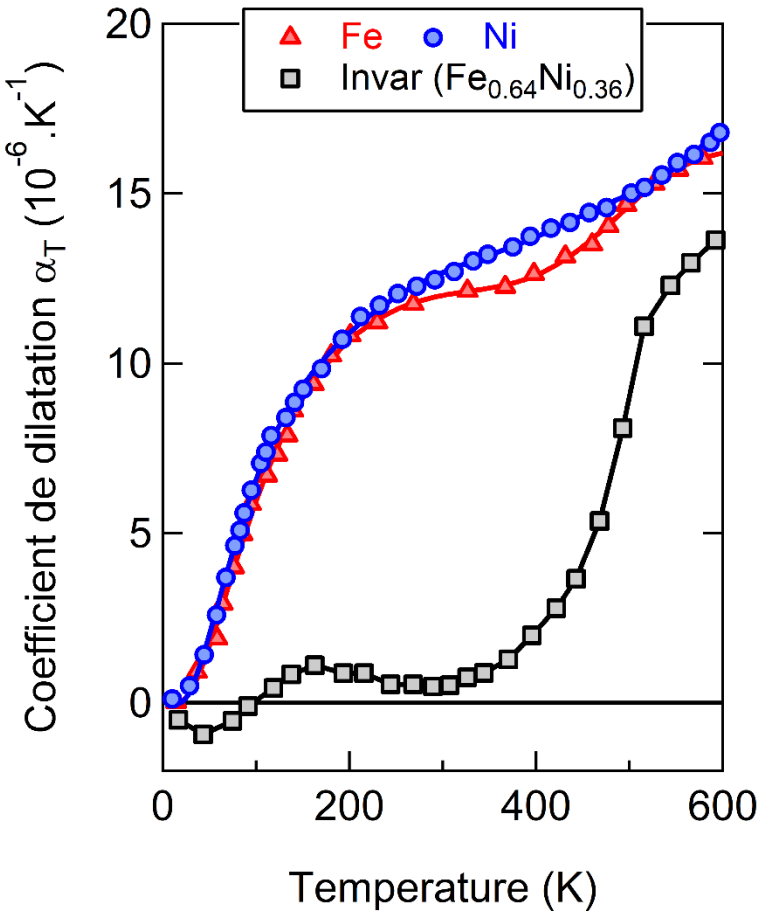
Pression



Volume



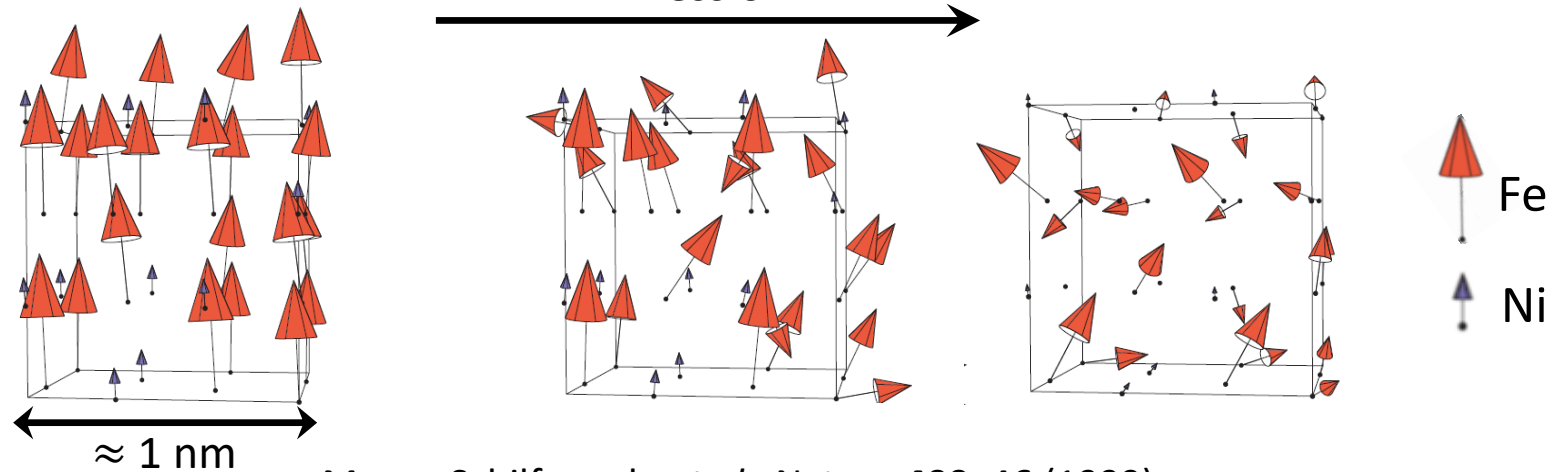
Thème 3: Textures magnétiques et effet 'Invar'



- Recherche par SANS/SAXS
- Taille et organisation spatiale vs. T, P
- Structuration sous champ magnétique
- Dynamique de spin

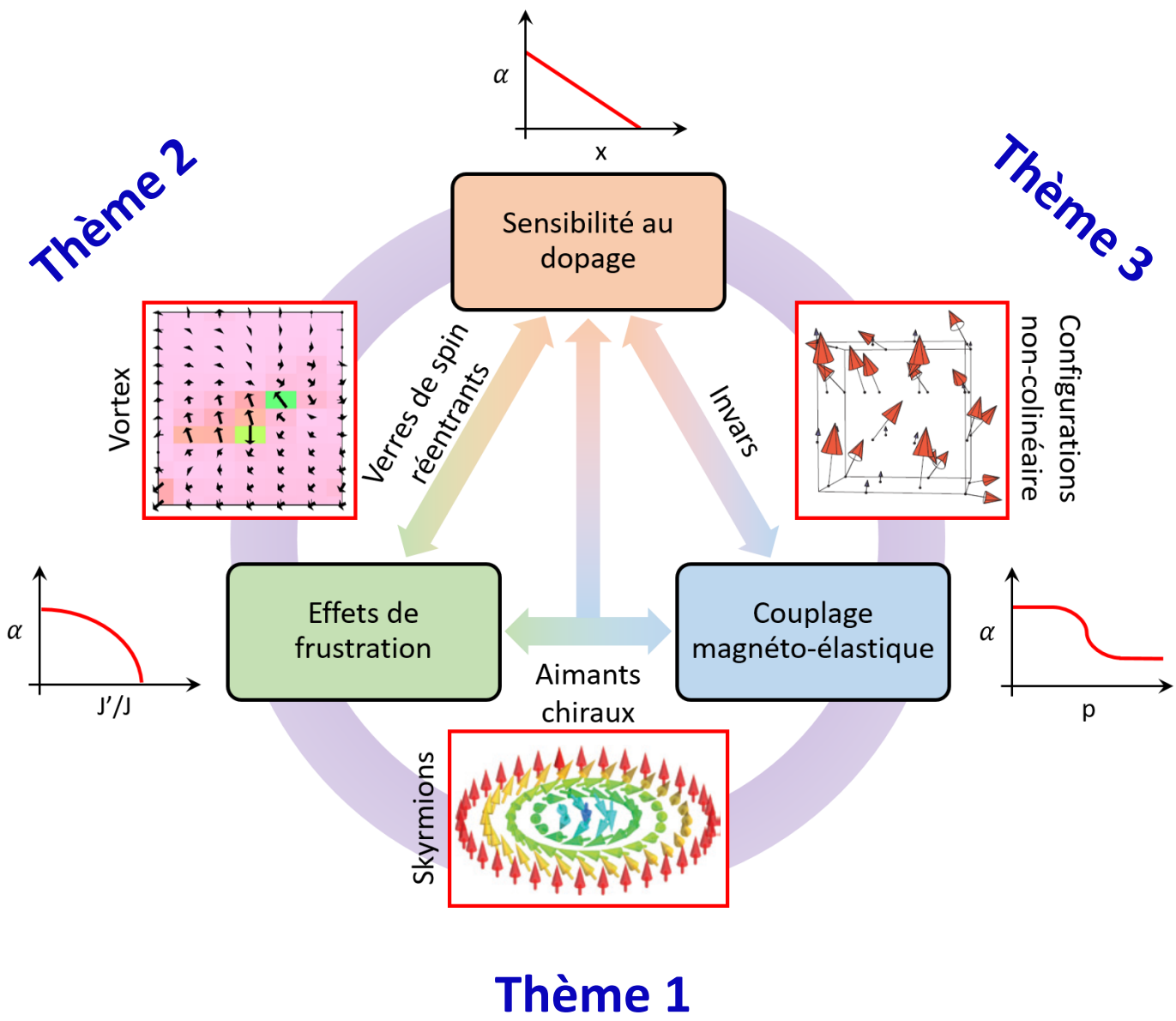
Court terme

Moyen terme



M. van Schilfgarde *et al.*, Nature **400**, 46 (1999)

Des thèmes en synergie et des collaborations



Théorie / Simulations

U.K. Roessler



Leibniz Institute for Solid State and Materials Research Dresden

S. Mankovsky



LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

A.O. Leonov



HIROSHIMA UNIVERSITY


I. Abrikosov




LINKÖPINGS UNIVERSITET

Synthèse d'échantillons

C. Decorse

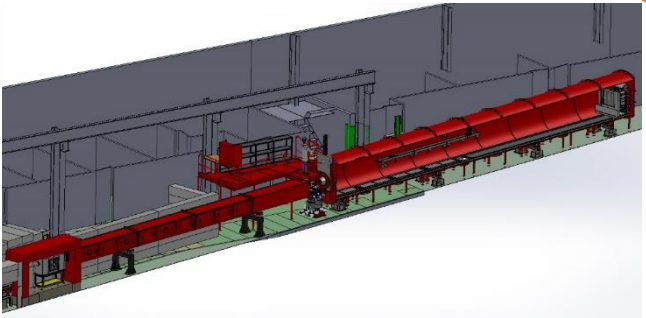


A.V. Tsvyashchenko



Institute for High Pressure Physics, Moscow

Une recherche accompagnant les innovations techniques



Une recherche accompagnant les innovations techniques

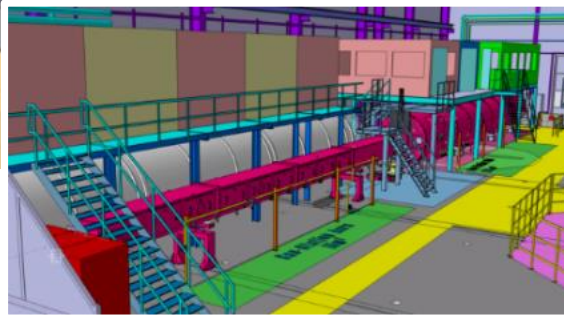
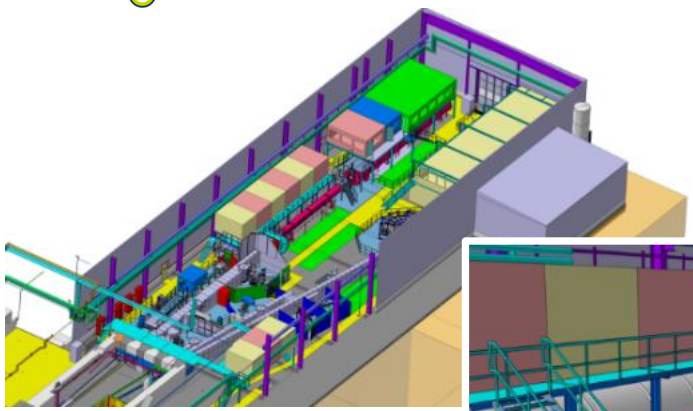


'Outstation' (2021)

PA20 @ PSI (SANS)



Villigen, Suisse



Une recherche accompagnant les innovations techniques

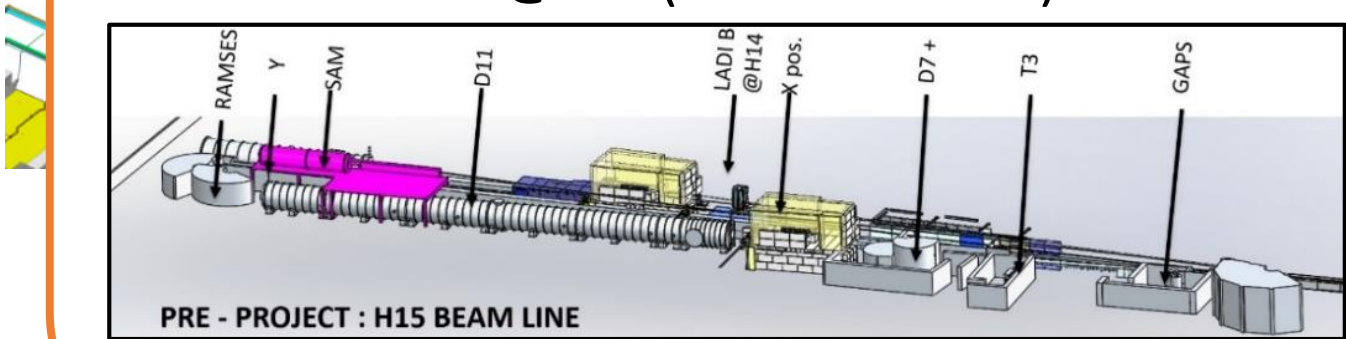
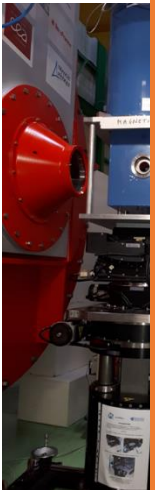


'Outstation' (2021)

'Outstation' (2022-2023)



SAM @ ILL (SANS + MIEZE)



Une recherche accompagnant les innovations techniques



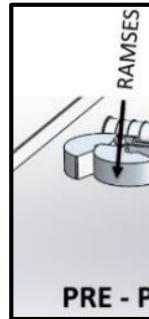
'Outstation' (2021)



'Outstation' (2022-2023)



Nouvelle source européenne (post 2023)



Lund, Suède

→ Faisceau neutronique le plus intense au monde:
petits échantillons = hautes pressions (> 10
Gpa) et physique de surface

Une recherche s'appuyant des équipements de pointe

Neutrons

Diffusion aux petits angles, diffraction et spectroscopie



NEUTRONS FOR SOCIETY



Heinz Maier-Leibnitz Zentrum



EUROPEAN SPALLATION SOURCE



Muons

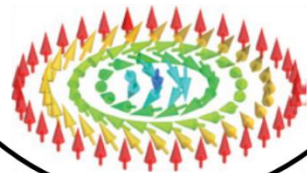
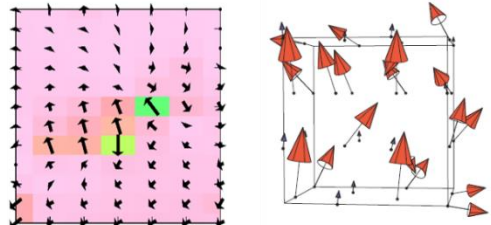
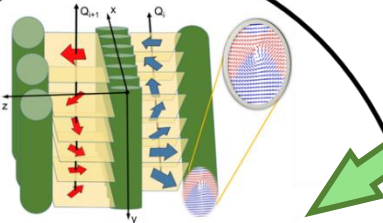
Fluctuations magnétiques locales



PAUL SCHERRER INSTITUT



Laboratoire Léon Brillouin



Rayons X (synchrotron)

Diffraction et spectroscopie sous haute pression



Equipements de laboratoire

Magnétométrie et diffusion de rayons X aux petits angles (SAXS)



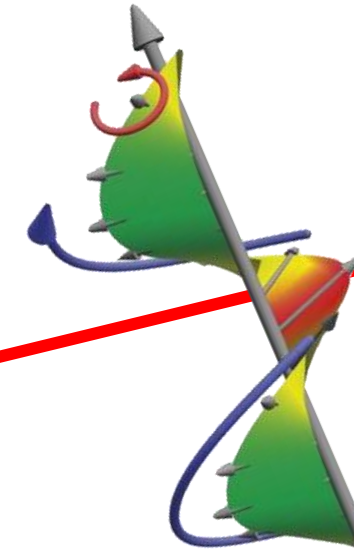
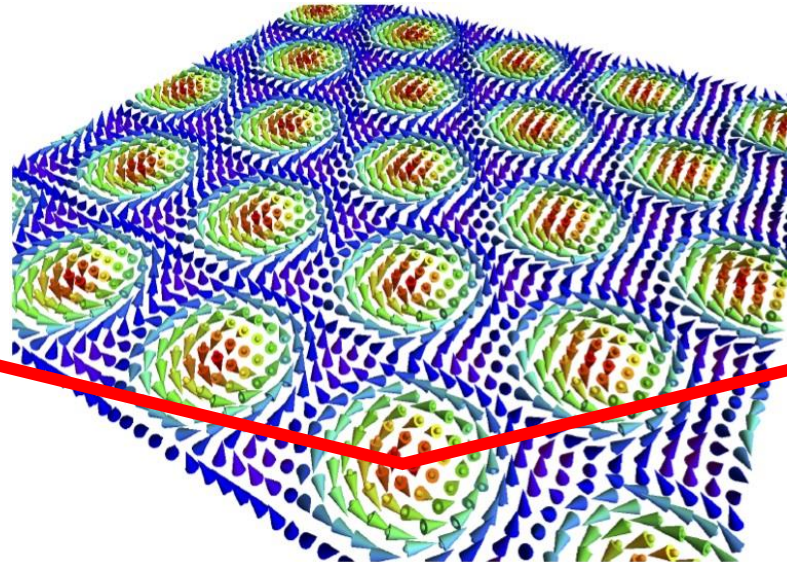
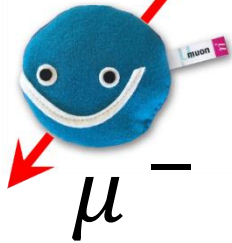
Nicolas MARTIN



université
PARIS-SACLAY

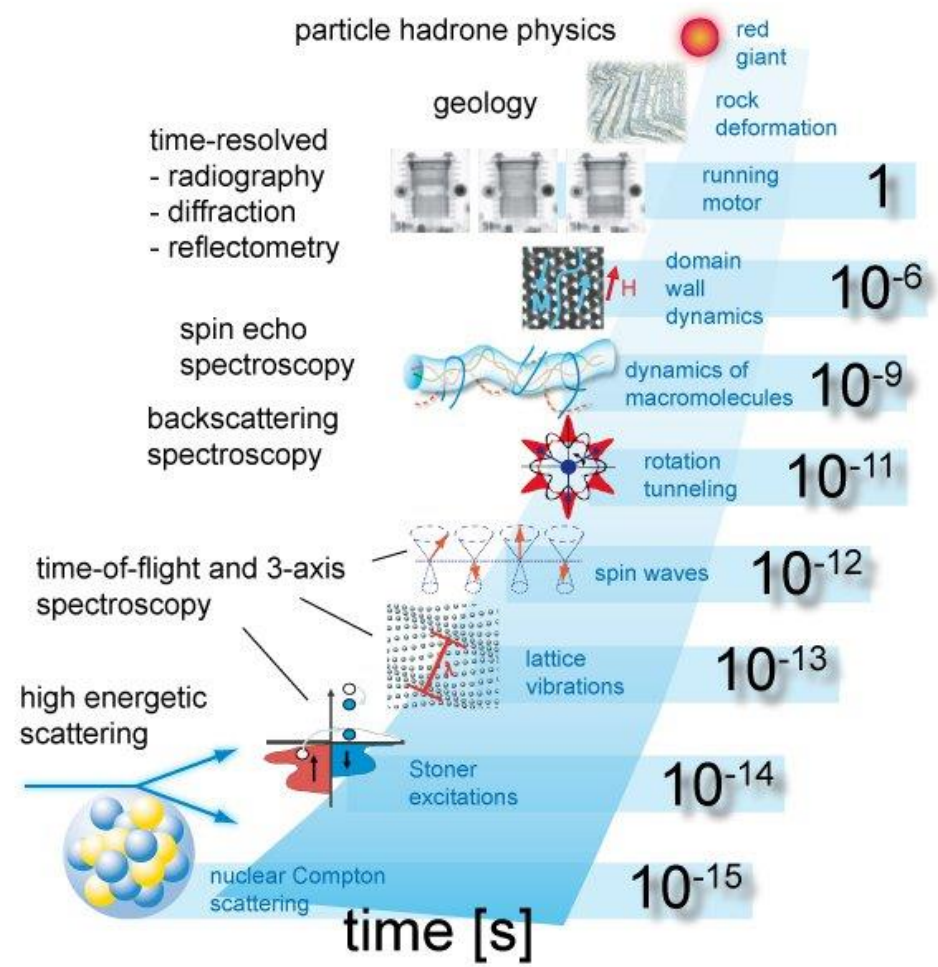
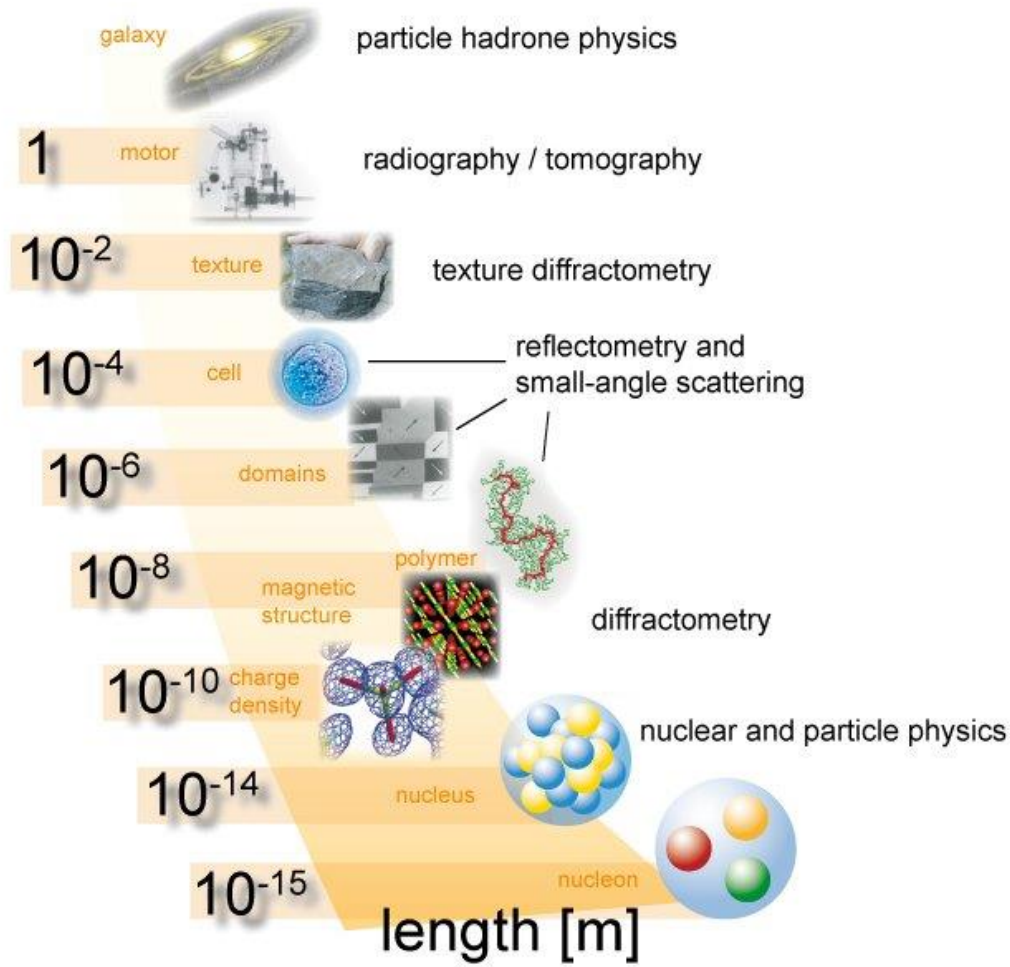


Textures et défauts topologiques magnétiques: propriétés statiques et dynamiques



Audition concours CRCN 03/02 – 1^{er} Avril 2019

Spectroscopie neutronique – espace (Q,ω)



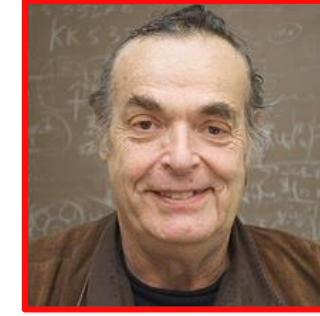
Spectroscopie MIEZE – principes (1)

- Quasi-elastic spectroscopy @ sub- μeV resolution

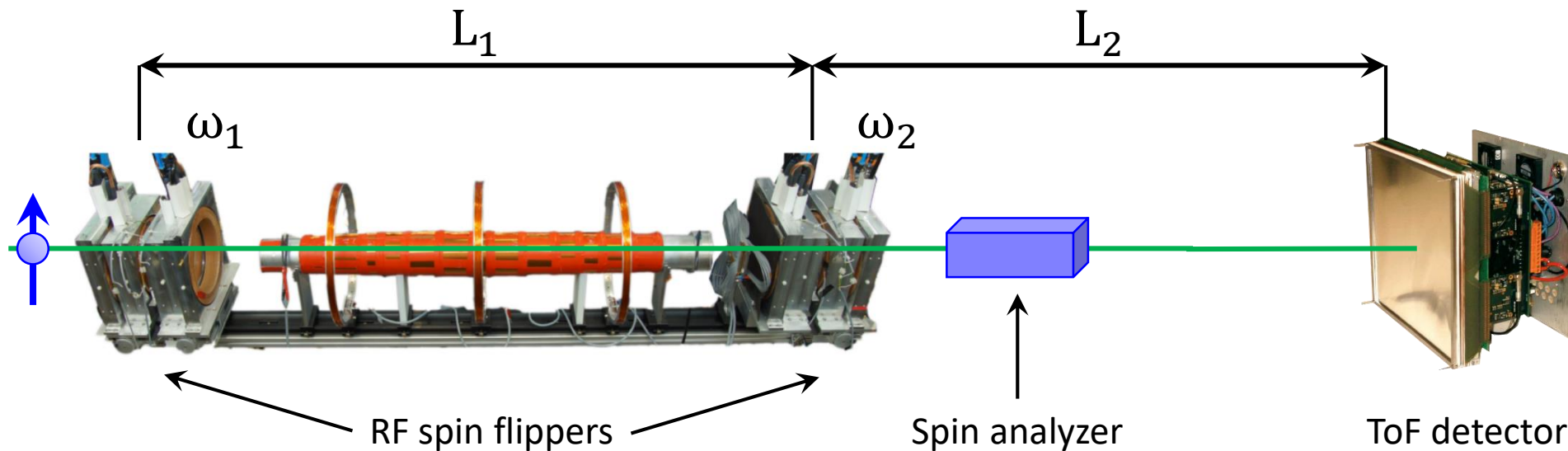
The incoming polarized neutron beam is manipulated by a pair of radio-frequency (RF) spin flippers running at frequencies ω_1 and $\omega_2 \rightarrow$ oscillation of neutrons' spin at a frequency $\omega_M = 2 \cdot (\omega_2 - \omega_1)$



R. Gähler, ILL



R. Golub, HMI
(now NYC University)



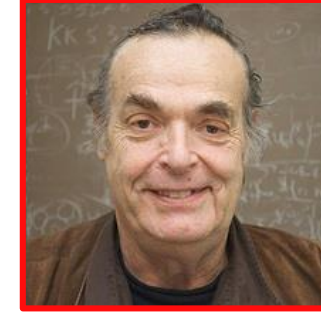
Spectroscopie MIEZE – principes (2)

- Quasi-elastic spectroscopy @ sub- μeV resolution

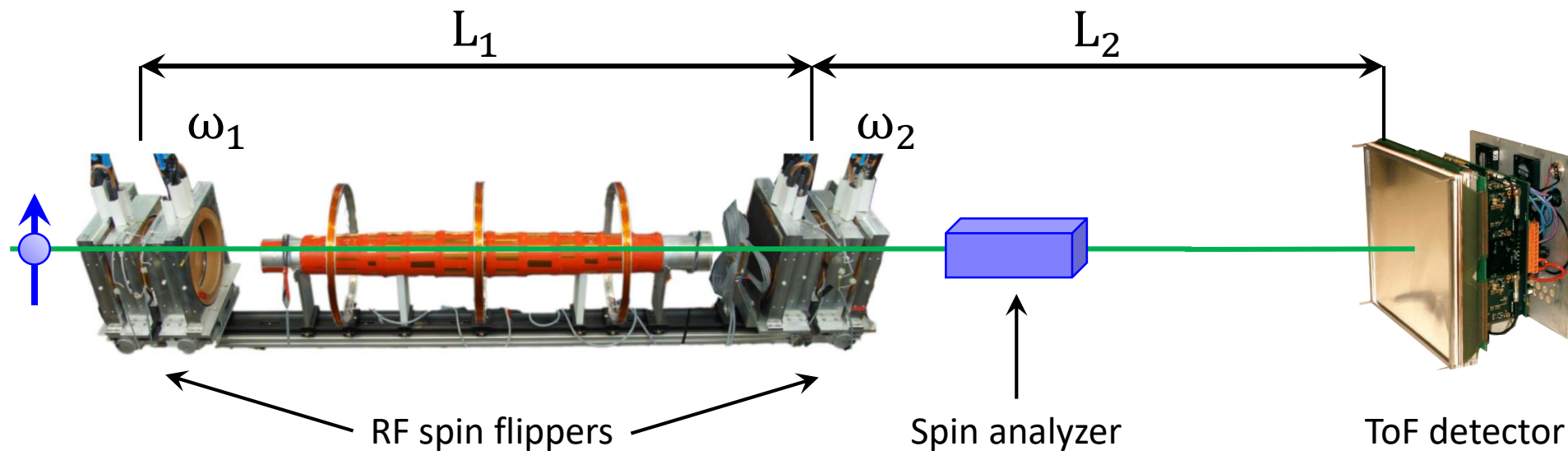
This time-dependent precession is converted into an **intensity modulation** by the spin analyzer.



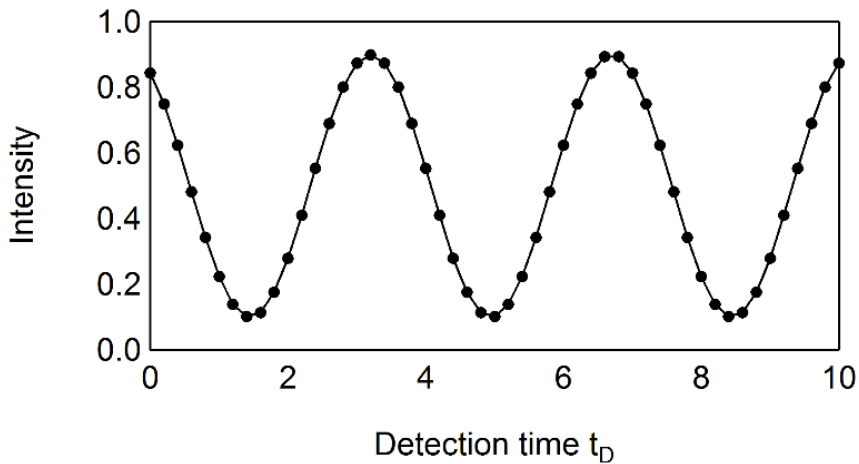
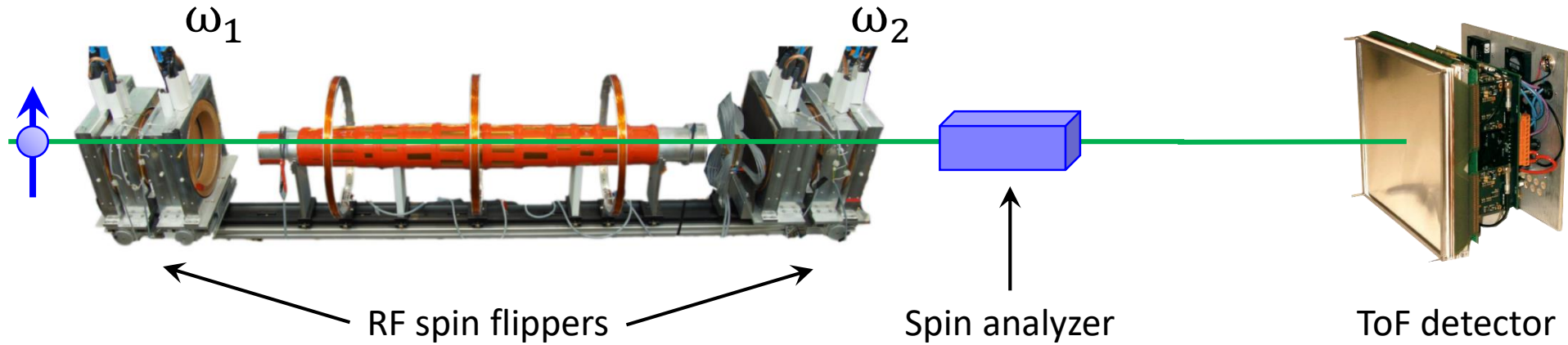
R. Gähler, ILL



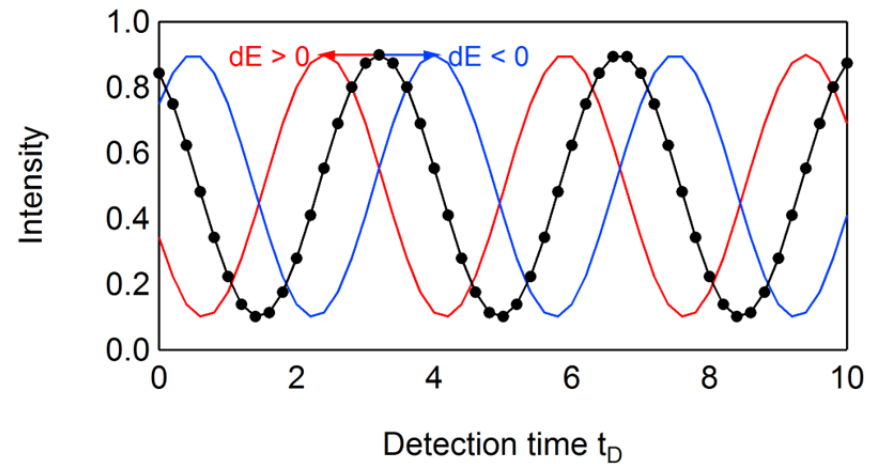
R. Golub, HMI
(now NYC University)



Spectroscopie MIEZE – principes (3)

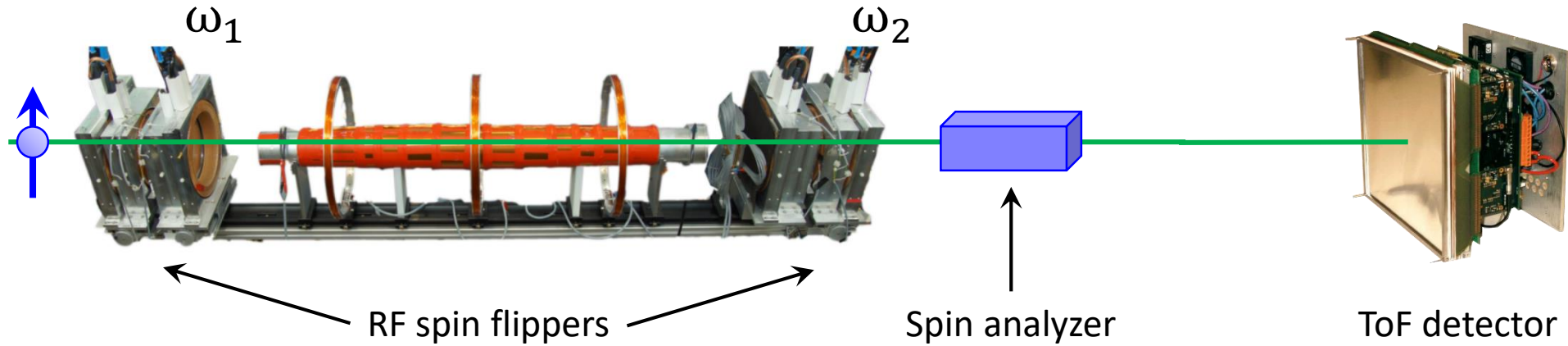


No scattering → harmonic intensity modulation at the detector

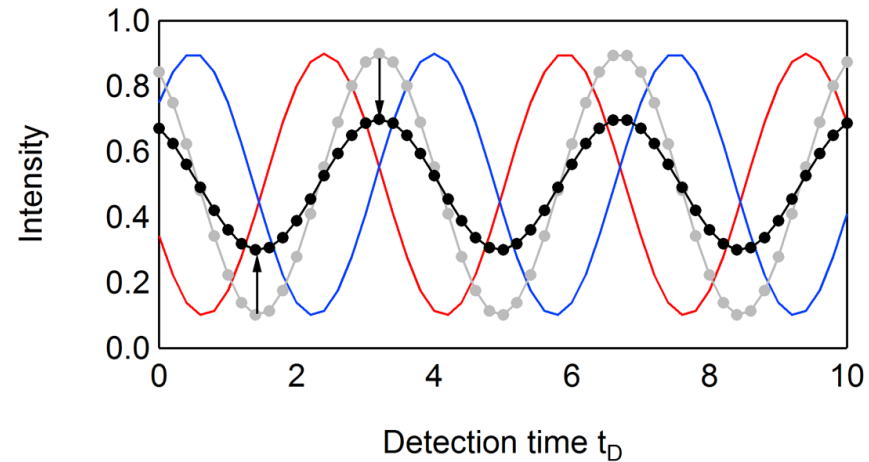


Quasi-/inelastic scattering process at the sample → distribution of neutron propagation time

Spectroscopie MIEZE – principes (4)



→ Signal contrast proportional to $S(q, \tau)$ i.e. the time-Fourier transform of the scattering function $S(q, \omega)$



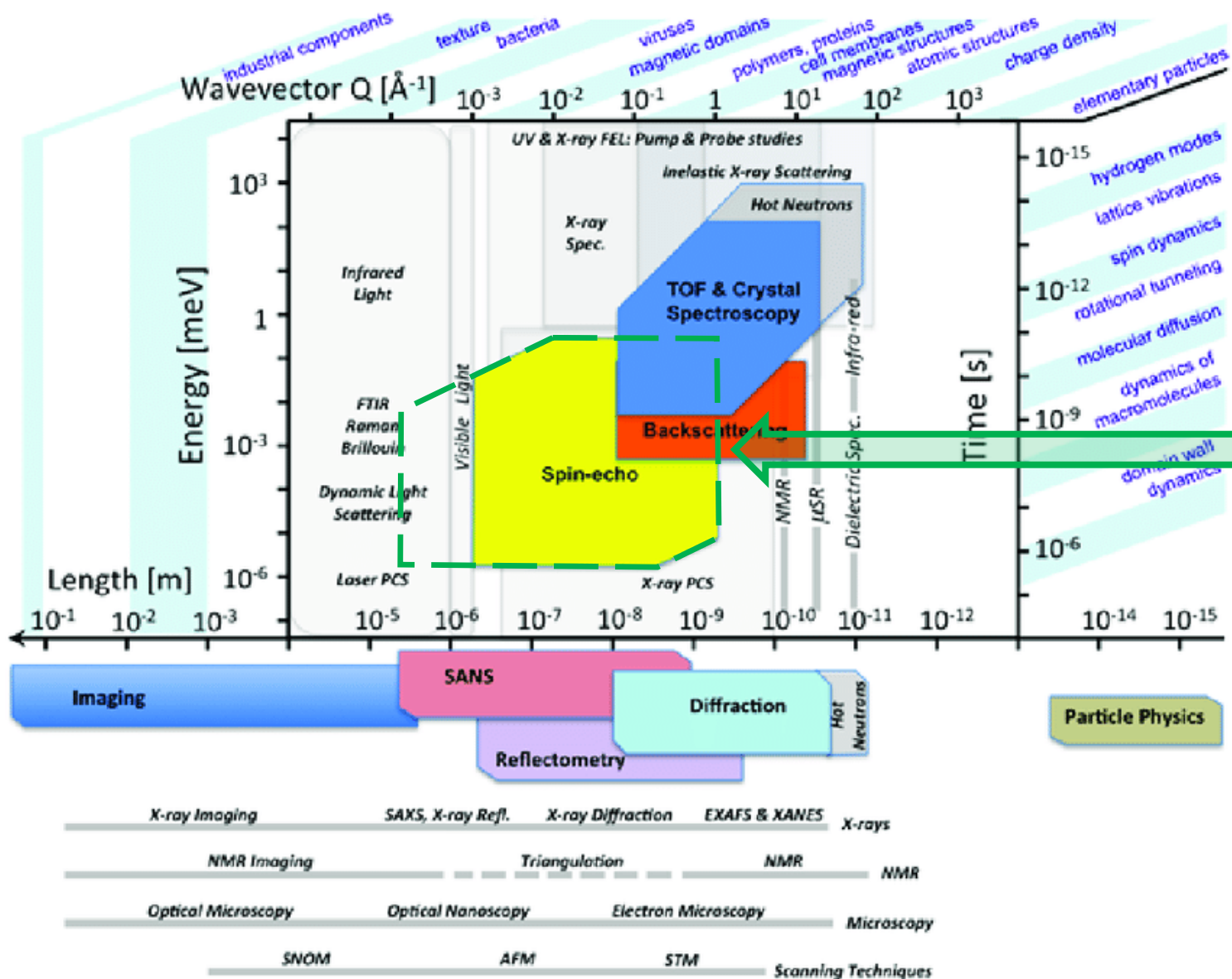
Spectroscopie MIEZE – principes (4)

→ Si
S
tr
fu

- The Fourier time τ (proportional to ω_M and $\bar{\lambda}^3$) quantifies the time/energy resolution. It can reach the 100 ns –range, which corresponds to a few neV resolution
- Unlike ‘traditional’ neutron spin echo (NSE) spectroscopy, MIEZE is insensitive to beam depolarization at the sample position. One can achieve high resolution under large magnetic fields, with protonated or magnetically disordered samples, *etc.*

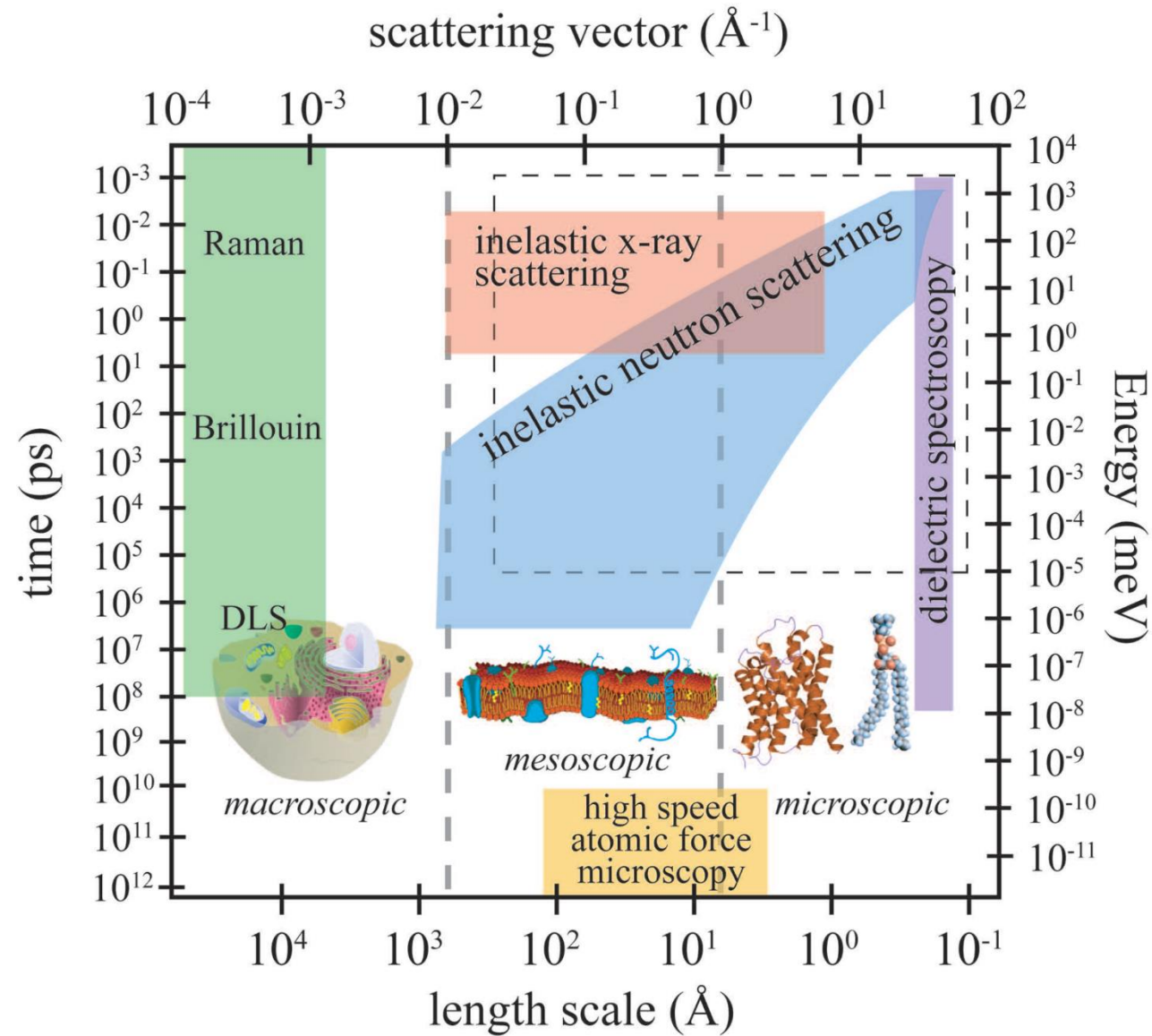
Detection time t_D

Spectroscopie MIEZE dans l'espace (Q,ω)

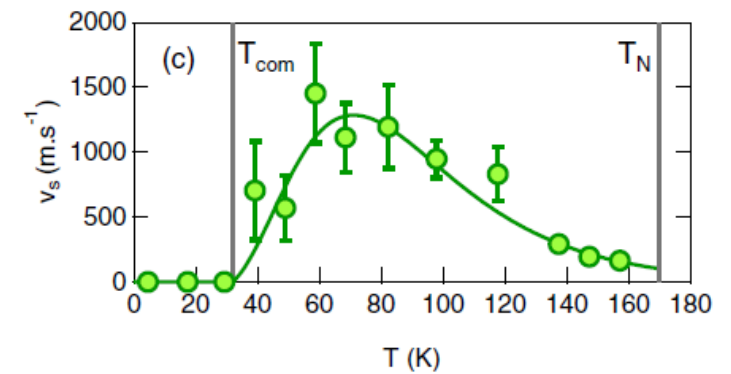
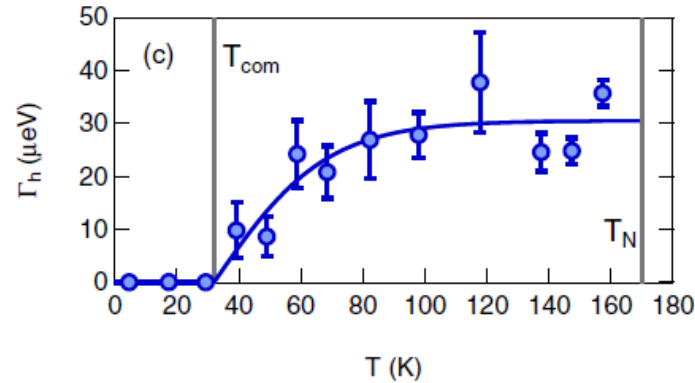
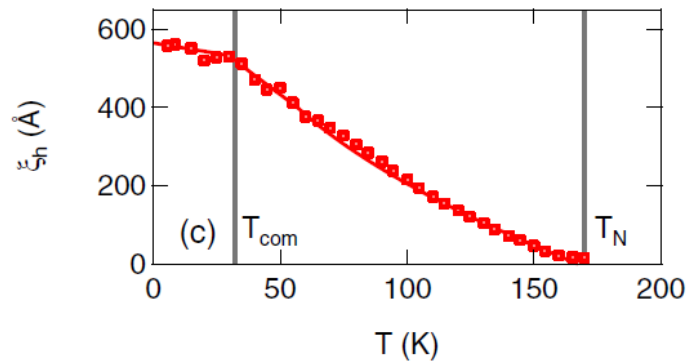
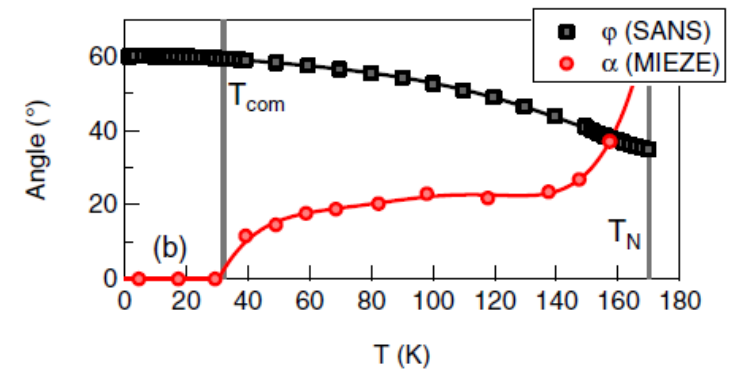
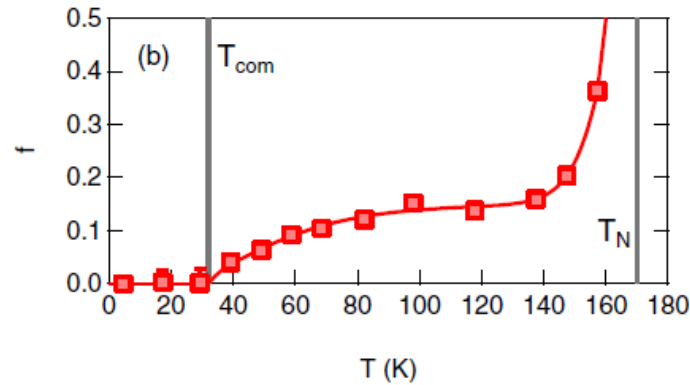
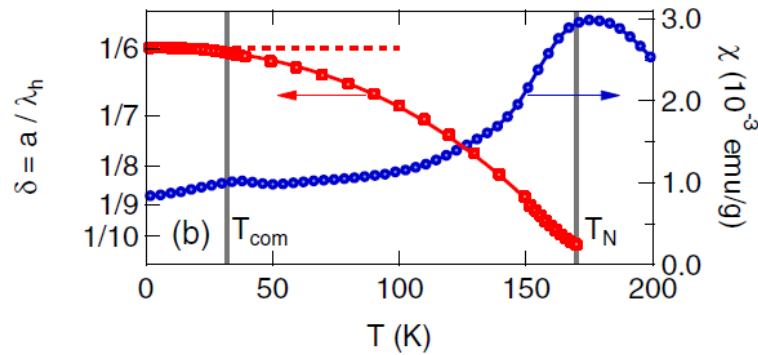
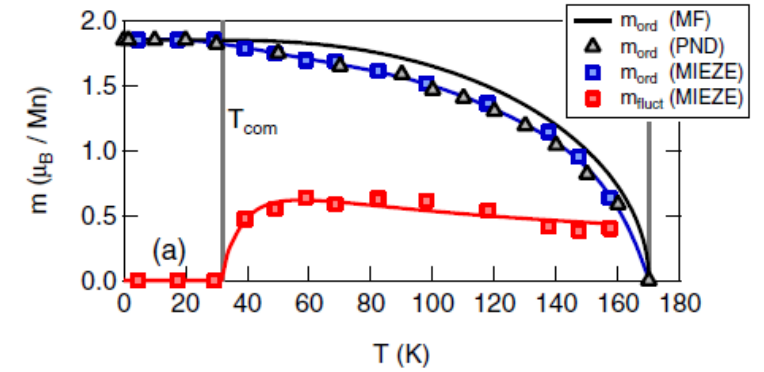
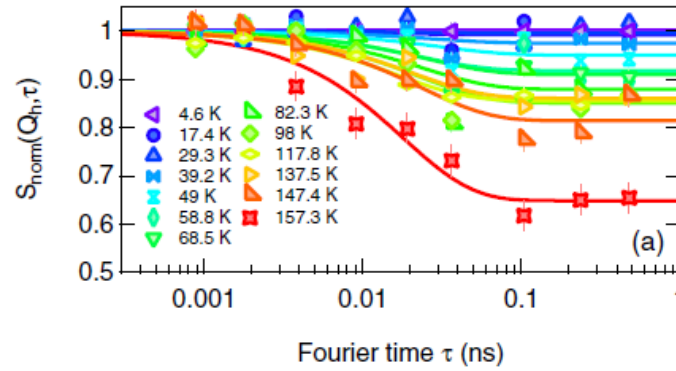
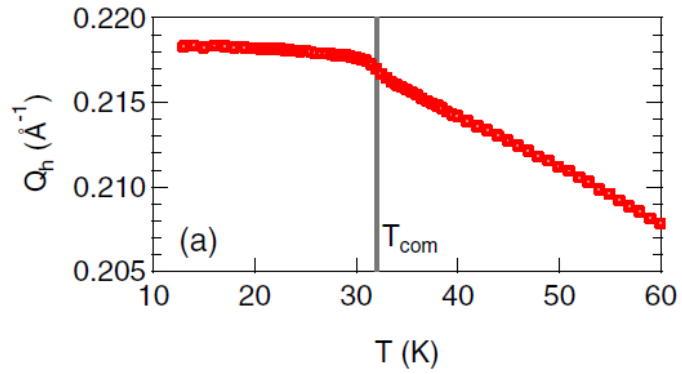


MIEZE:
SANS + H et P

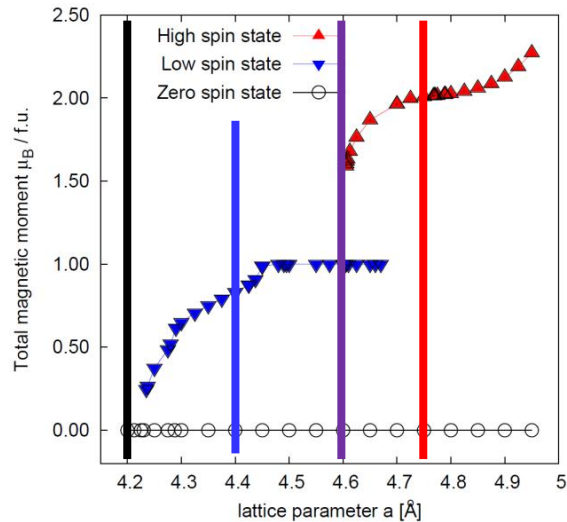
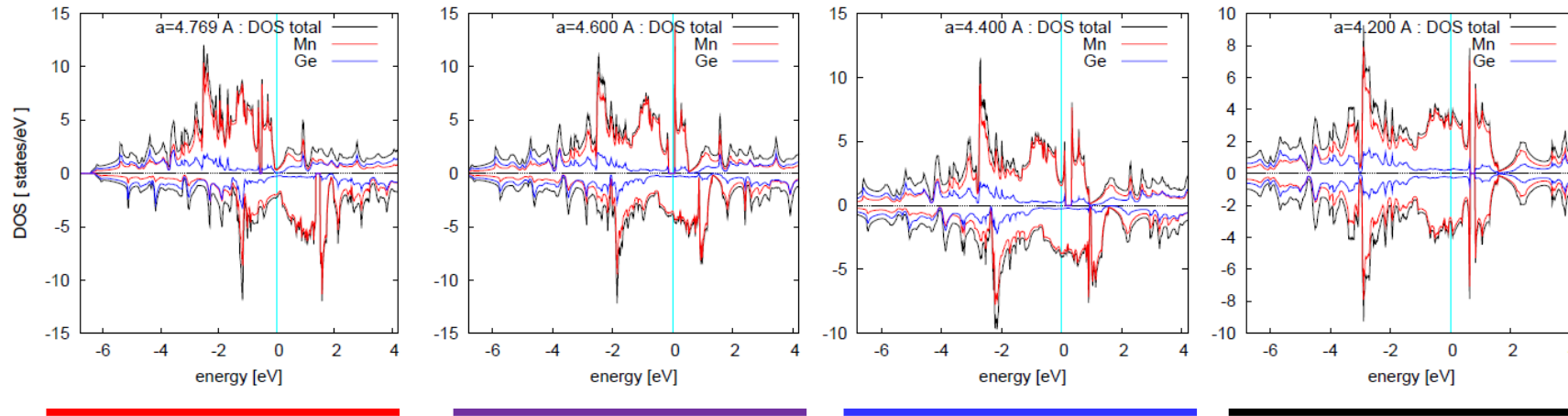
Spectroscopie neutronique – espace (Q,ω)



MnGe – dynamique de spin vue par MIEZE

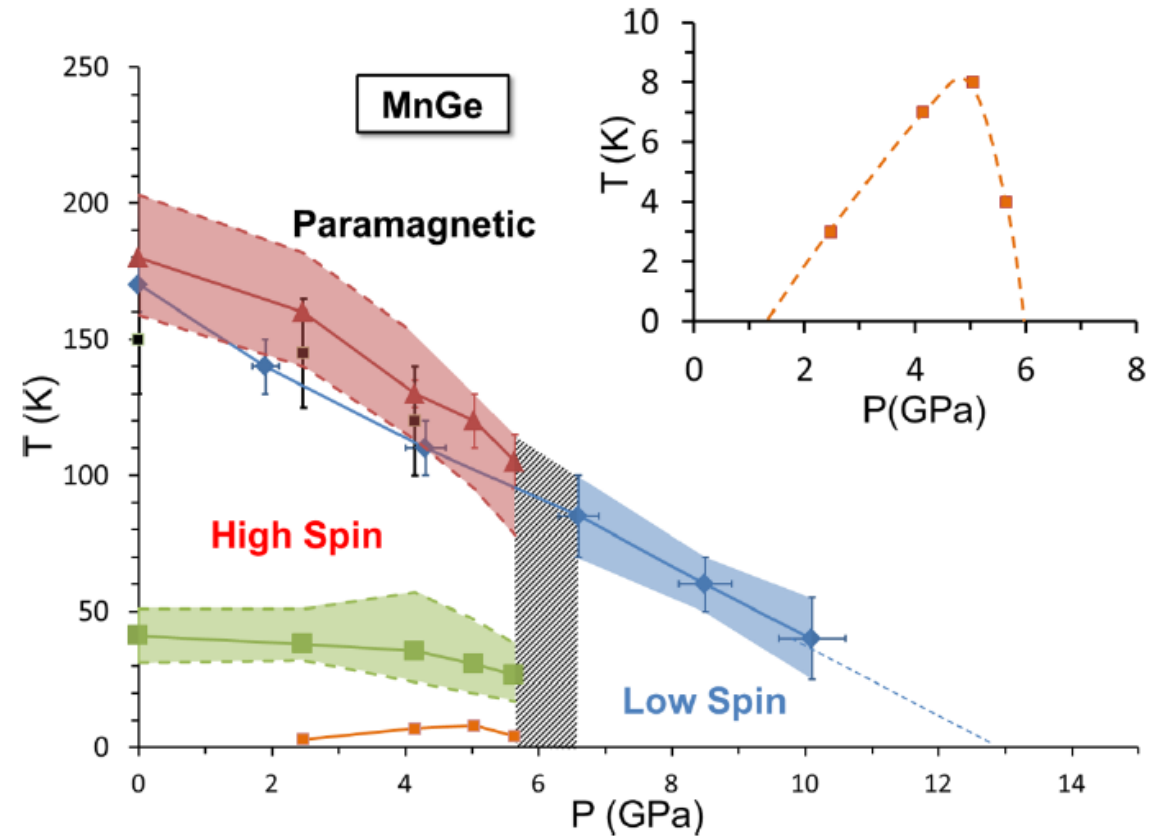
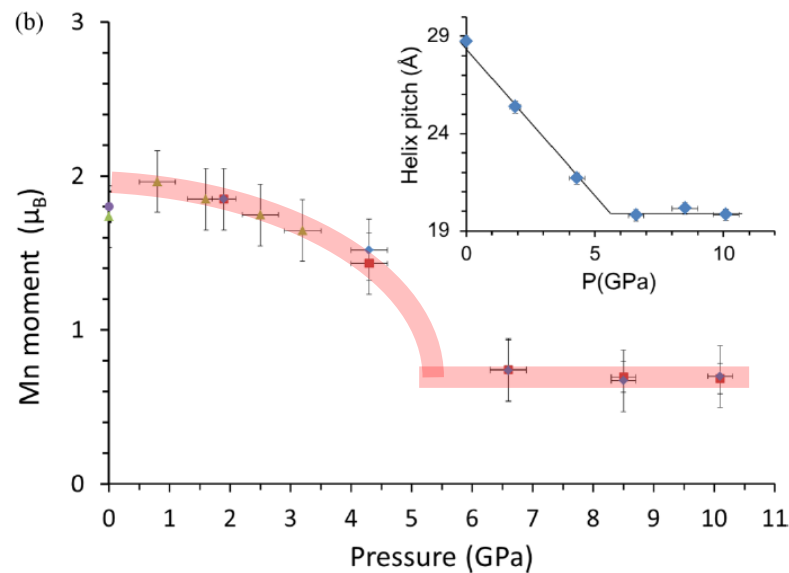
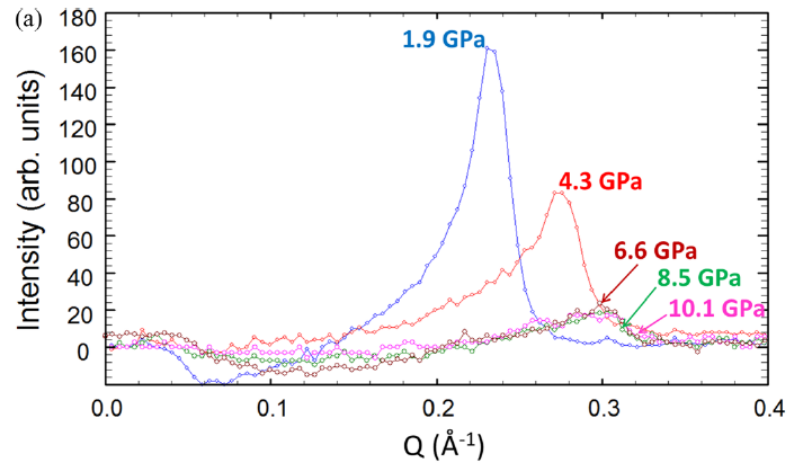


MnGe – Transition haut-spin/bas-spin (théorie)

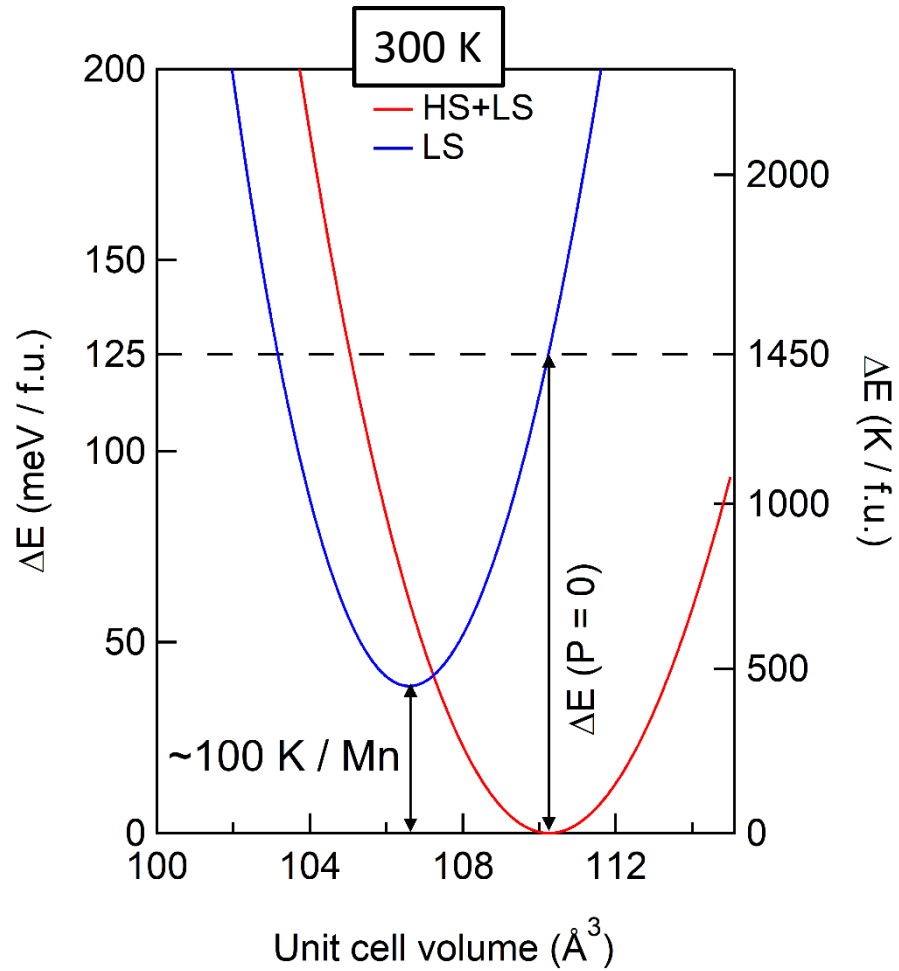


- Ambient pressure state:
High-spin (HS) with $m \approx 2 \mu_B / \text{Mn}$ (metal)
- Intermediate compression range ($P > 18 \text{ GPa}$):
 - (i) Low-spin (LS) with $m \approx 1 \mu_B / \text{Mn}$ (semi-metal)
 - (ii) Low-spin (LS) with decreasing m (metal)
- High pressure ($P > 75 \text{ GPa}$):
Zero-spin (ZS), $m = 0$ (metal)

MnGe – Transition haut-spin/bas-spin (expérience)

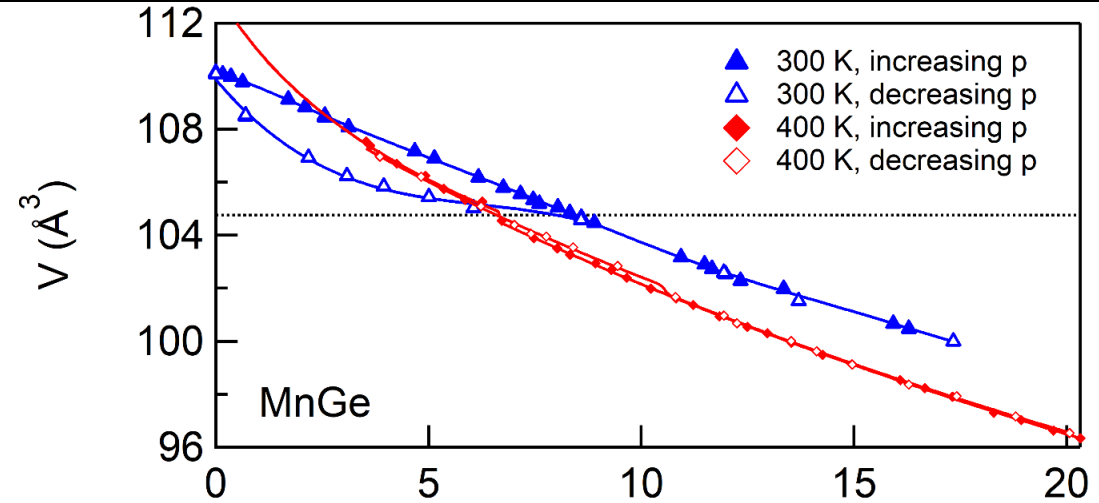


MnGe – Equations d'état sous pression

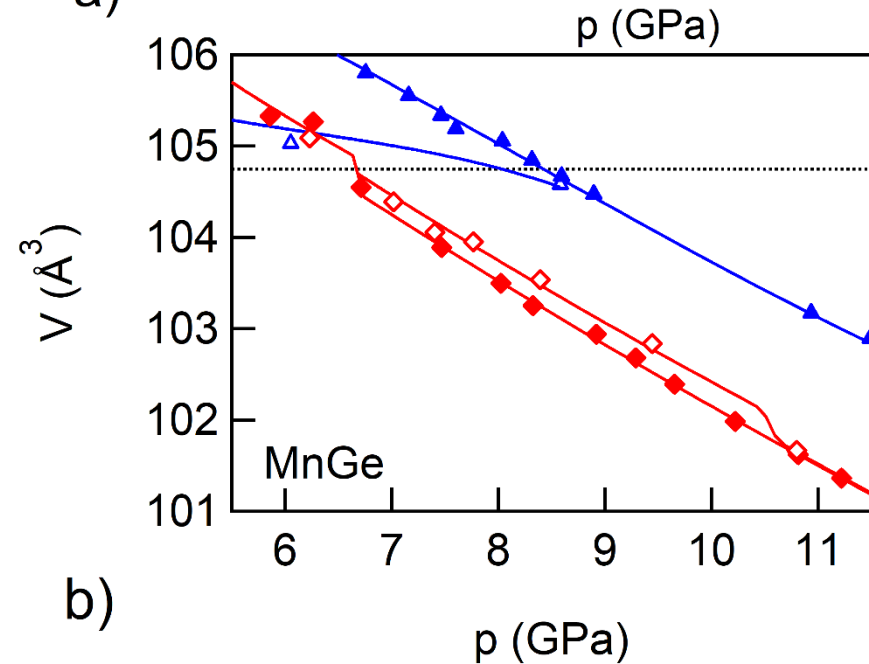


$$p = - \frac{\partial E}{\partial V}$$

N. Martin et al., Phys. Rev. B **93**, 214404 (2016)



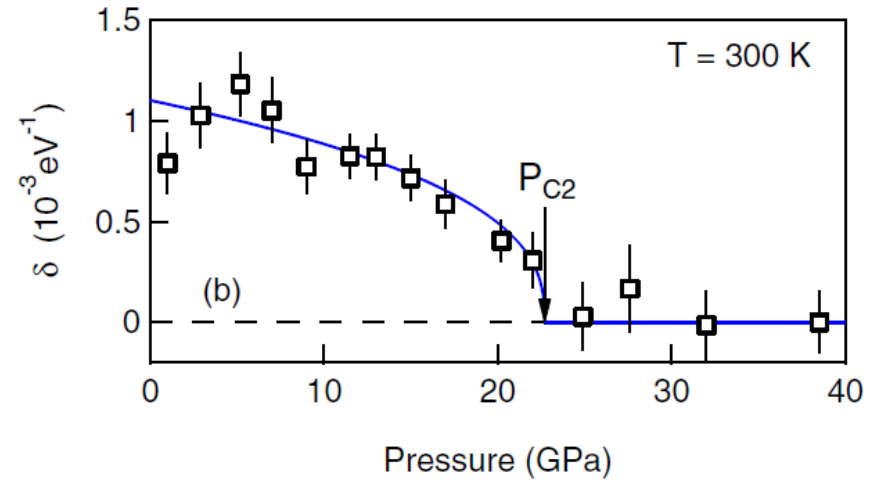
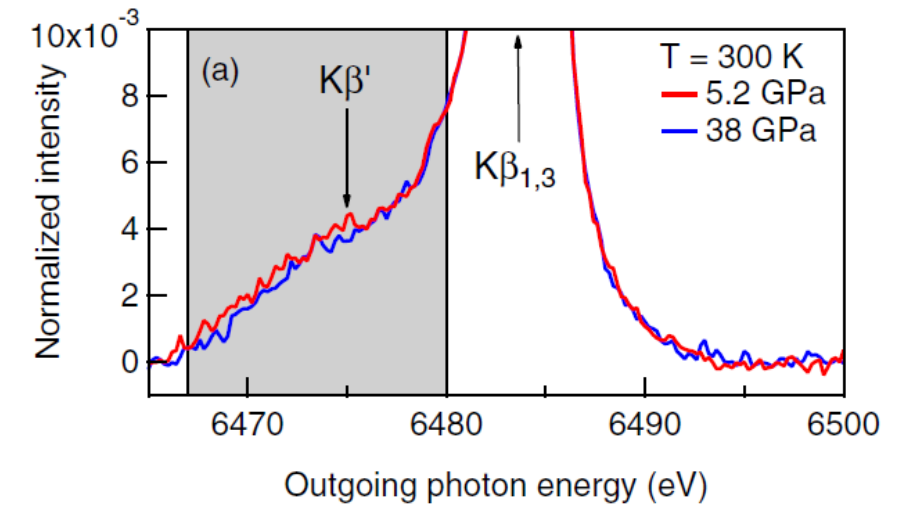
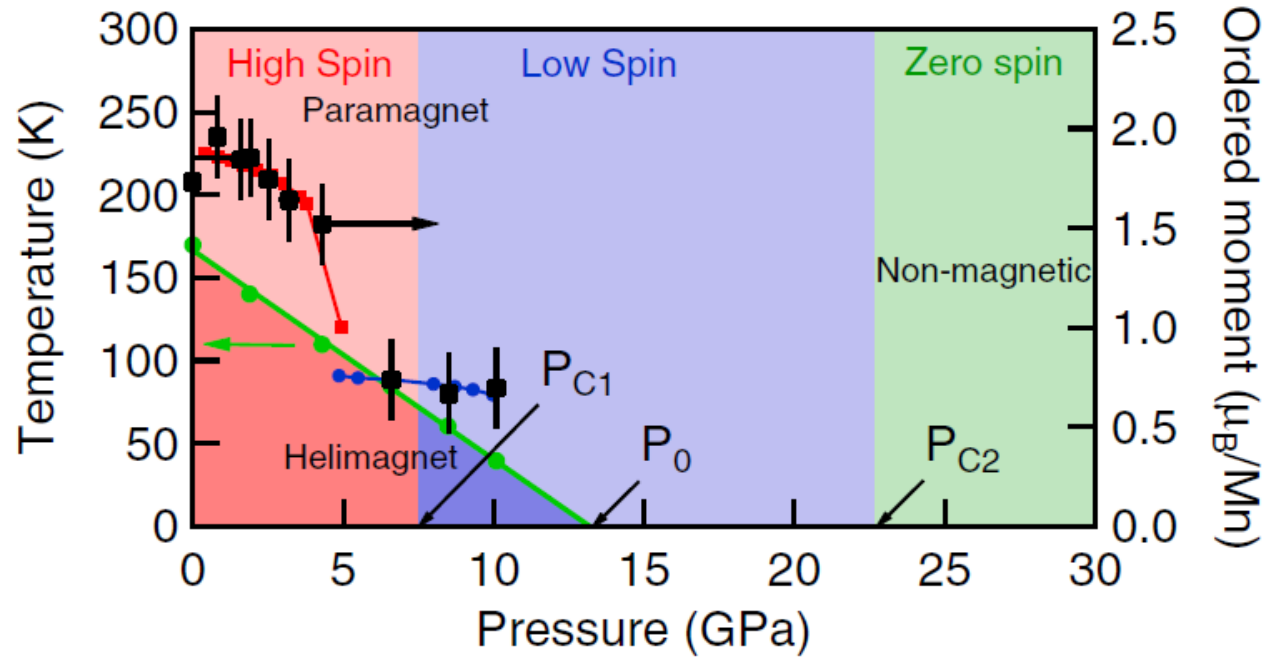
a)



b)

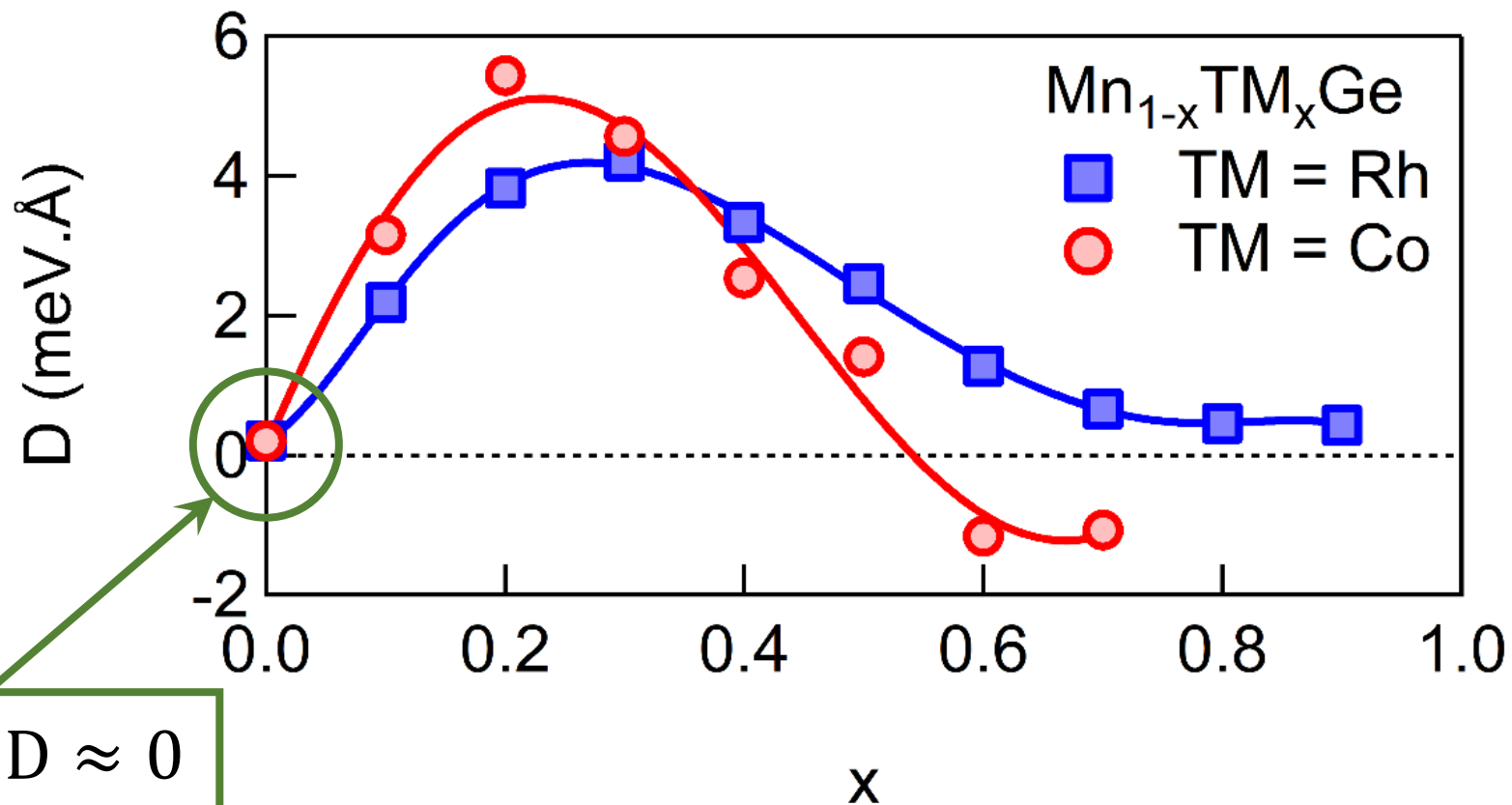
N. Martin et al., résultats non publiés

MnGe – Moment local vs. P par HAXPES



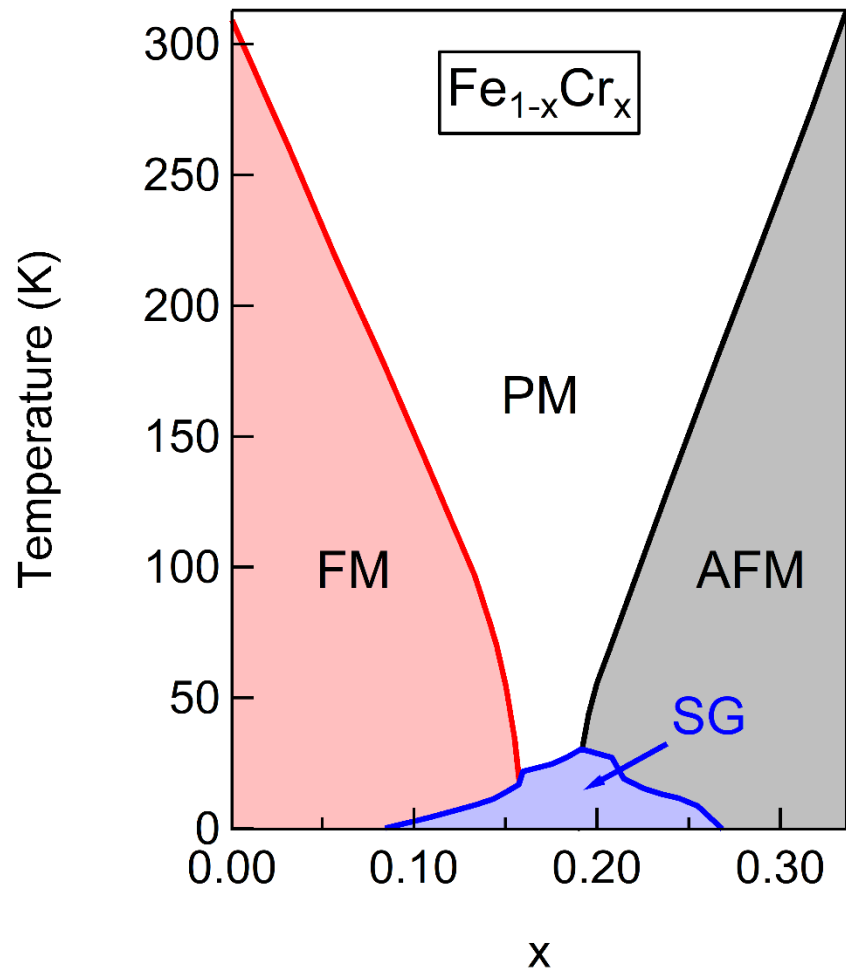
N. Martin *et al.*, Phys. Rev. B **93**, 214404 (2016)

DMI vs. x dans $\text{Mn}_{1-x}(\text{Co,Rh})_x\text{Ge}$

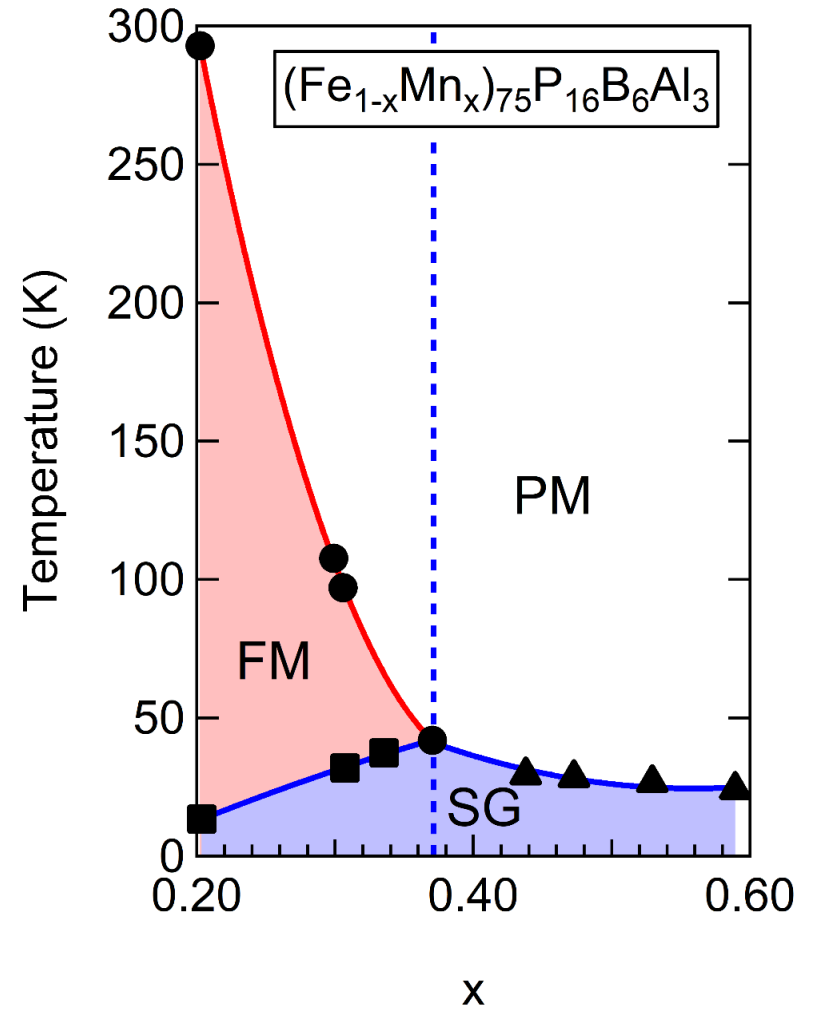


S. Mankovsky (Ludwig-Maximilians-Universität, München), communication privée

Diagrammes de phase de $\text{Fe}_{1-x}\text{Cr}_x$ et $\alpha\text{-Fe}_{1-x}\text{Mn}_x$

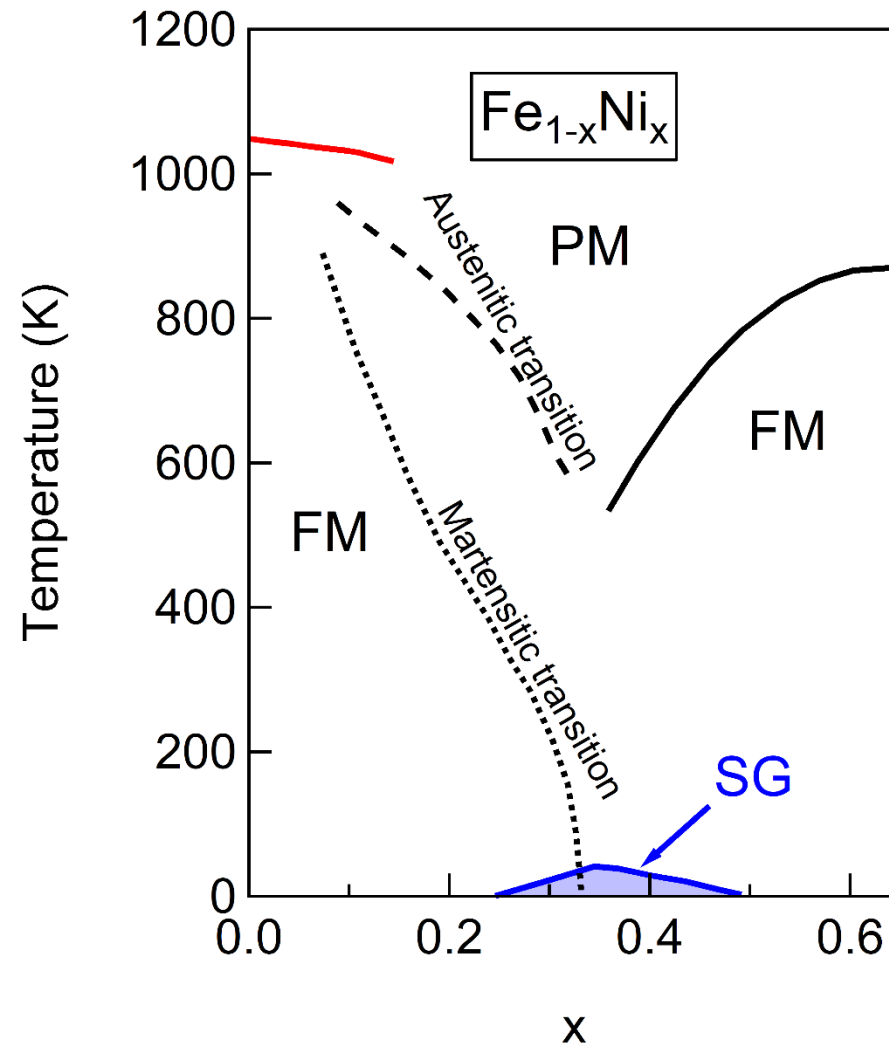


S.K. Burke *et al.*, J. Phys. F **13** (1983) 451-470



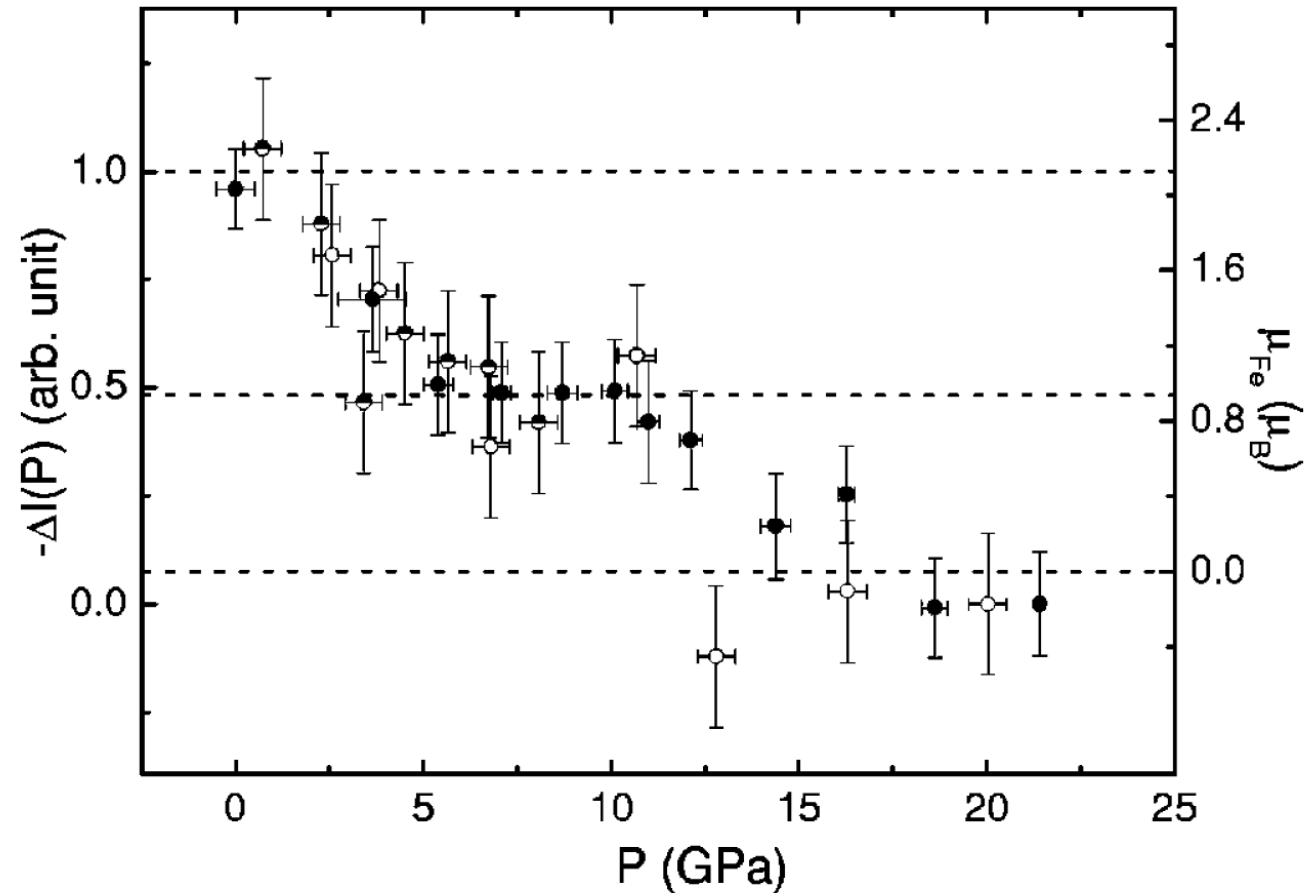
M.B. Salamon *et al.*, Phys. Rev. Lett. **44**, 596 (1980)

Diagramme de phase de $\text{Fe}_{1-x}\text{Ni}_x$



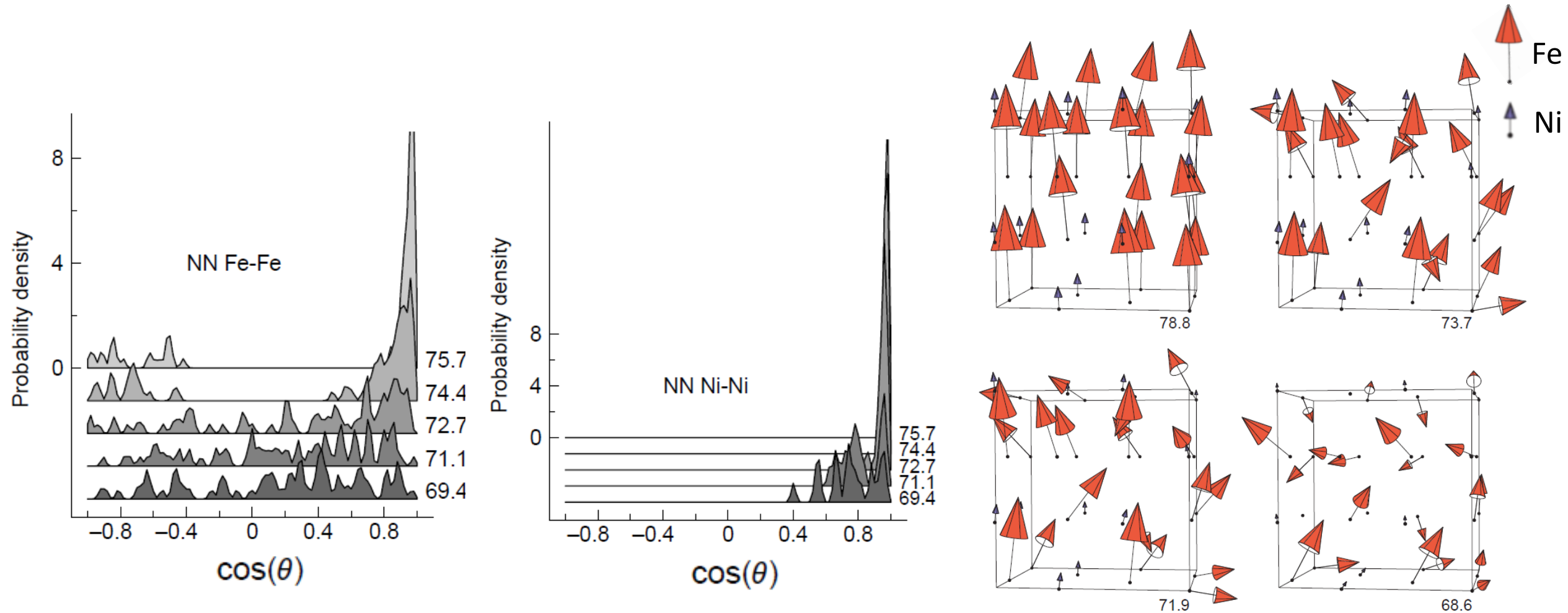
T. Miyazaki *et al.*, J. Appl. Phys. **57**, 3456 (1985)

$\text{Fe}_{0.64}\text{Ni}_{0.36}$ – Moment local vs. P par HAXPES



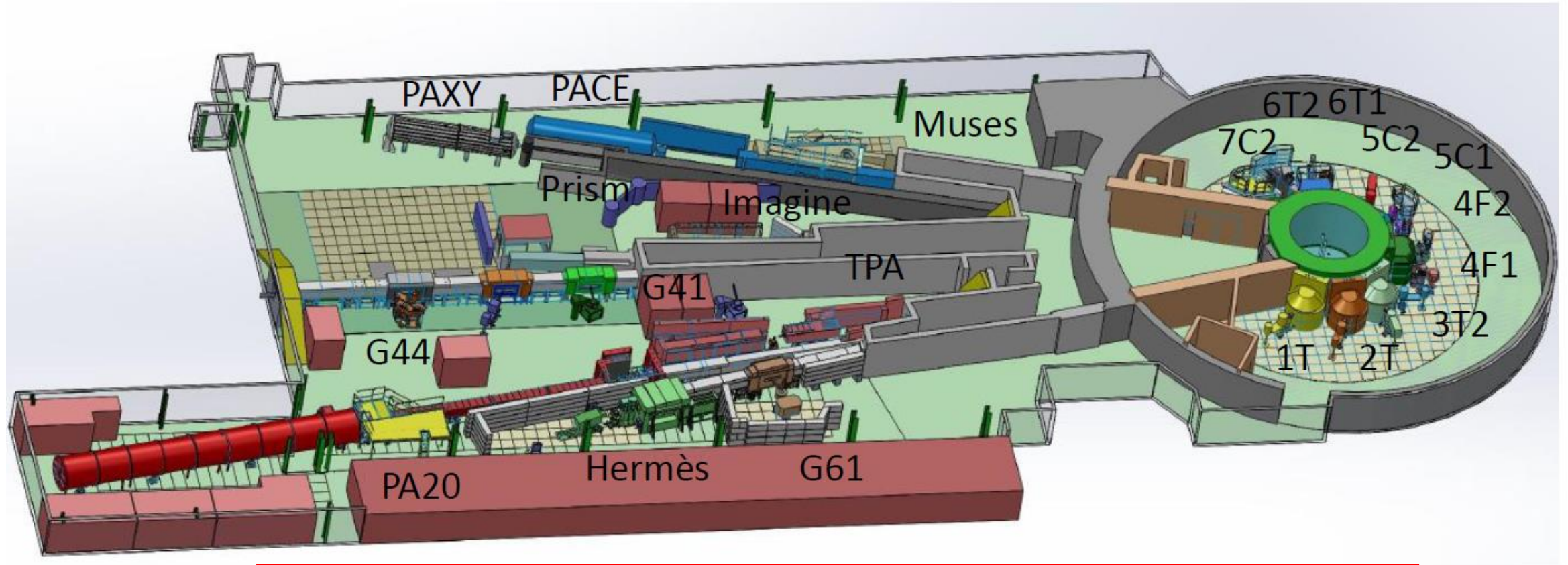
J.-P. Rueff *et al.*, Phys. Rev. B **63**, 132409 (2001)

$\text{Fe}_{0.64}\text{Ni}_{0.36}$ – Etat de spin du fer dans et configurations locales vs. p



M. van Schilfgaarde *et al.*, Nature **400**, 46 (1999)

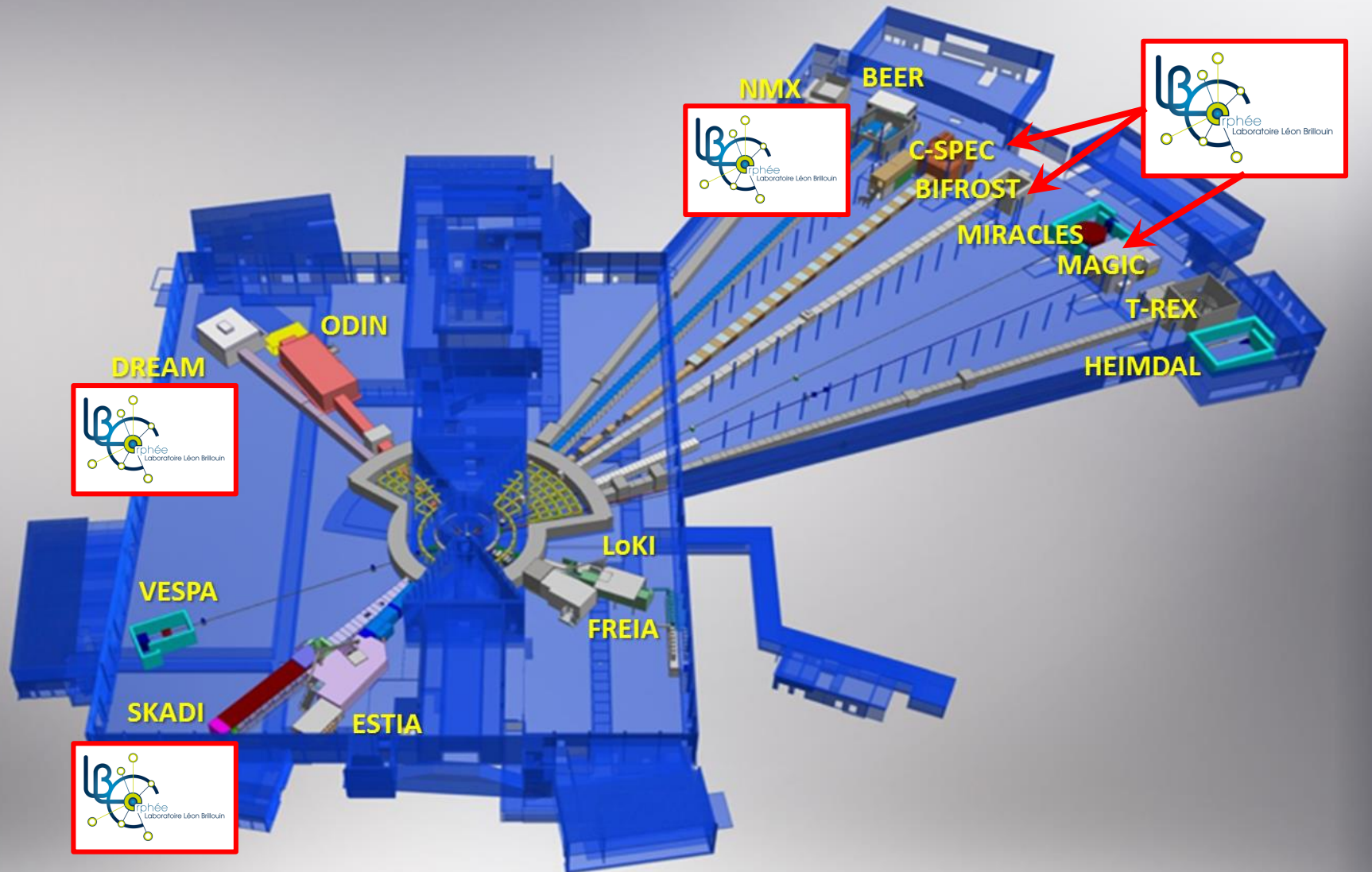
Laboratoire Léon Brillouin: instruments



21 instruments

- 9 diffractomètres
- 4 petits-angles
- 2 réflectomètres
- 4 spectromètres trois-axes
- 1 spin echo
- 1 station d'imagerie

European Spallation Source: instruments et contributions françaises



French contributions

MAGIC (60 %):

- Polarized single-crystal diffraction

C-SPEC (50 %):

- Cold ToF, direct geometry

SKADI (50 %):

- SANS

DREAM (24 %):

- Powder diffraction

BIFROST (22 %):

- ToF, indirect geometry

NMX (14 %):

- Diffraction for biophysics