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## Laser-Assisted Antiferromagnetic-Ferromagnetic Transition in FeRh

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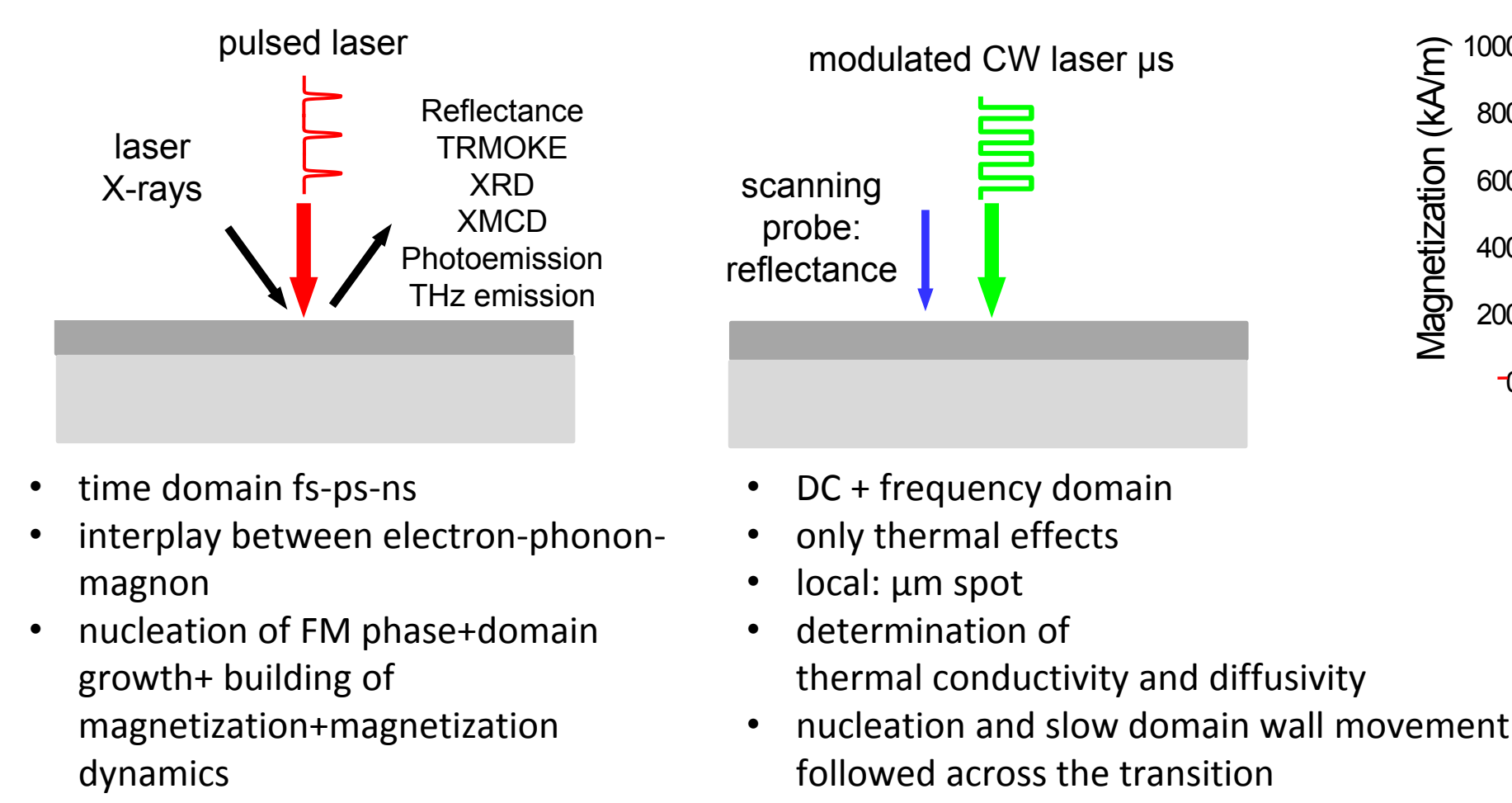
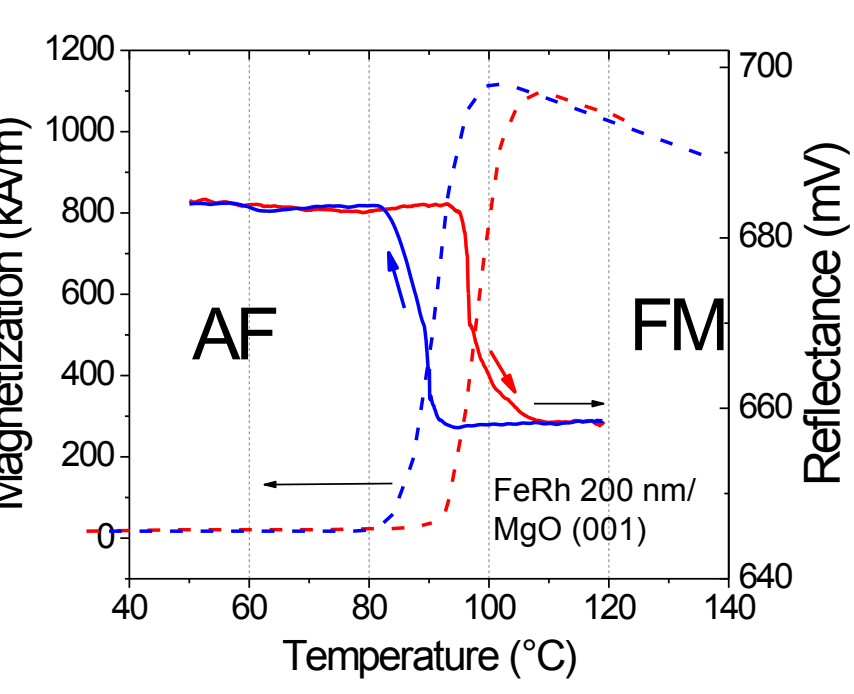
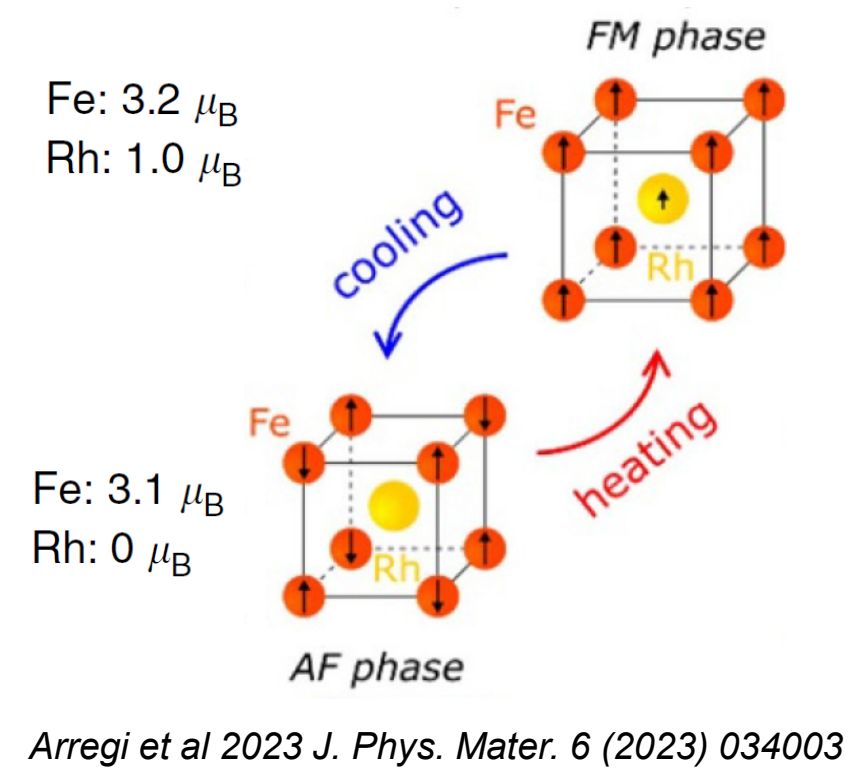


Among magnetic materials near equi-atomic FeRh alloys, with their antiferromagnetic (AF) to ferromagnetic (FM) magneto-structural hysteretic transition near room temperature, were studied long ago in bulk form [Kouvel, *JAP* 1962, Lewis, *J. Phys.D* 2016]. In the recent years they have aroused a renewed interest as thin films with particular focus on the tuning of their AF-FM transition [Arregi, *J. Phys. D*: 2018, Ceballos, *APL* 2017], the electrical detection of their magnetic state with application to information coding [Martí, *Nat. Mater.*, 2014], and their giant magneto-caloric effect [Nikitin, *Phys. Lett.* 1990, Manekar, *J. Phys. D* 2008].

FeRh is also a good candidate to investigate laser-assisted transient or irreversible first order phase transition. Lattice expansion, nucleation of FM domains and magnetization dynamics have been studied using ultrafast pump-probe techniques. Here we show that low frequency (~ 100 kHz) modulated reflectance experiments provide an insight, not only on thermal effects (thermoreflectance, determination of the thermal conductivity) but also on the laser-assisted AF-FM domain movement and reversible/irreversible nucleation of the FM phase across the full temperature range of the AF-FM transition.

## 1 FeRh: AF to FM transition

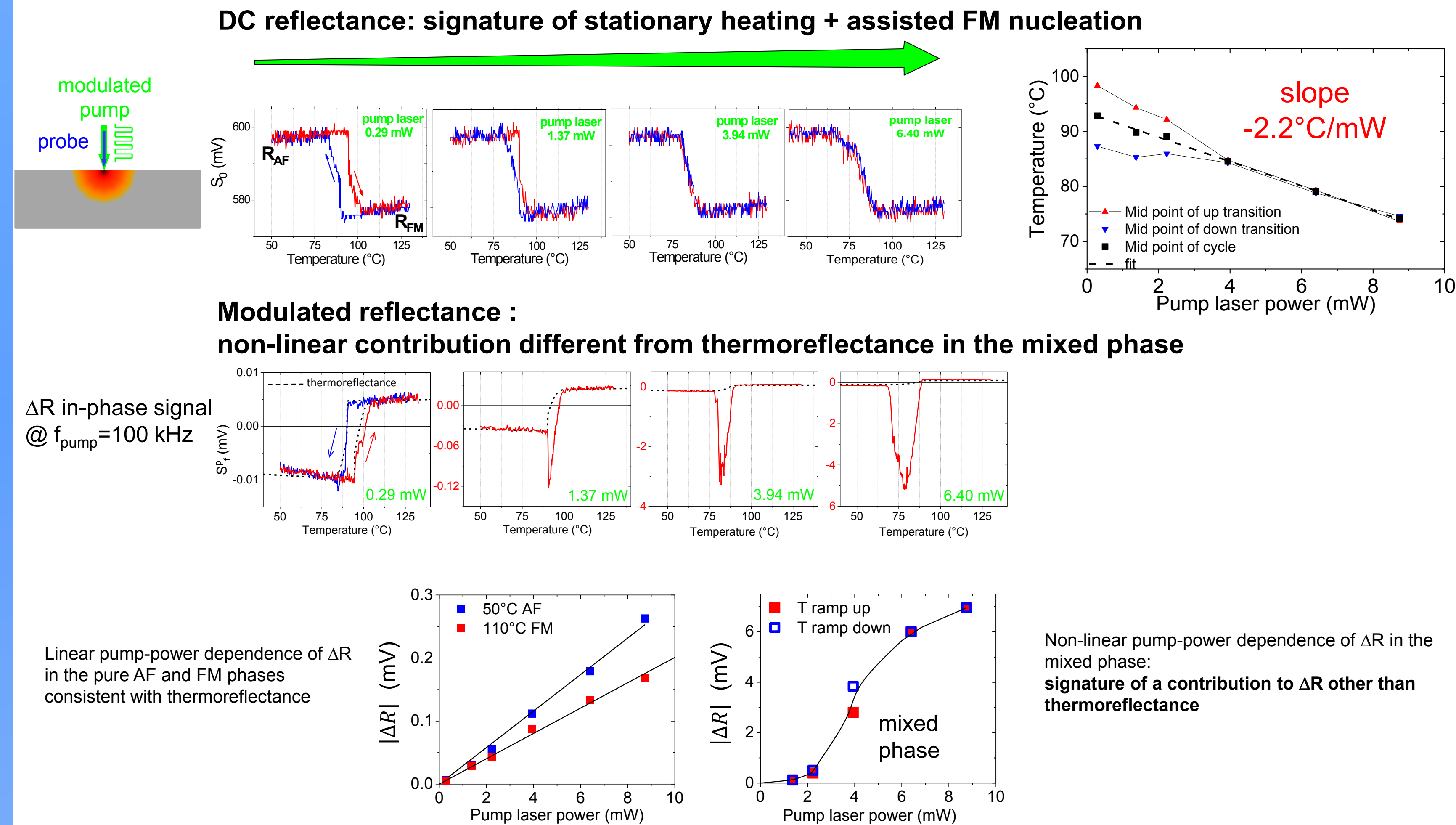
- Fe<sub>50</sub>Rh<sub>50</sub>: AF-FM transition close to room temperature
- isostructural transition but increase of the lattice parameter by 0.7 %
- change of the electronic structure
  - optical properties: 4% decrease of reflectivity from AF to FM
  - electrical properties: 40% drop of resistivity from AF to FM
- transition temperature tunable by
  - strain
  - magnetic field
- giant magnetocaloric effect
- information coding on two perpendicular AF states
- laser-induced transient phase transition (Ju et al., *PRL* 2004, Bergman, *PRB* 2006, Radu *PRB* 2010, Mariager, *PRL* 2012, Pressacco, *Str. Dyn.* 2018, *Nat. Commun.* 2021, Li, *Nat. Com.* 2022, *Matter Arxiv* 2023)



epitaxial FeRh films onto single-crystal MgO (001) substrates  
post-growth annealing to obtain the CsCl-type (B2 ordering) crystal structure  
cap layer Pt 2 nm

Sample growth at CEITEC by DC magnetron sputtering  
(V. Uhlir et al *Nat. Commun.* 7, 13113, (2016))

## 4 Mixed AF-FM phase: A huge contribution to the modulated reflectance other than thermoreflectance



## 5 Pump-modulated FM fraction x

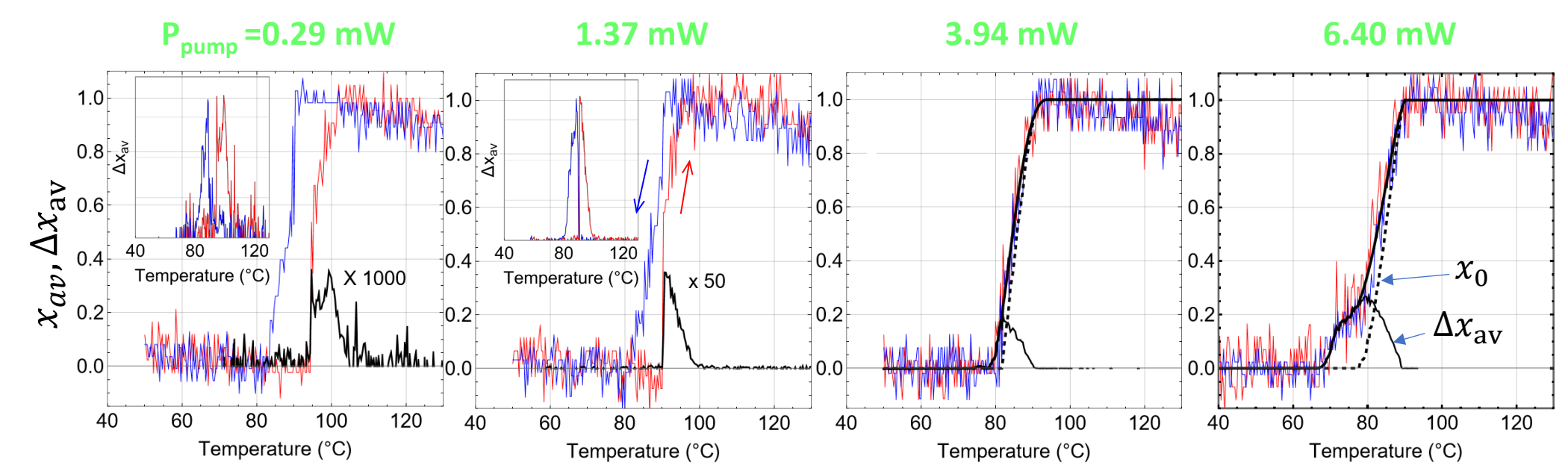
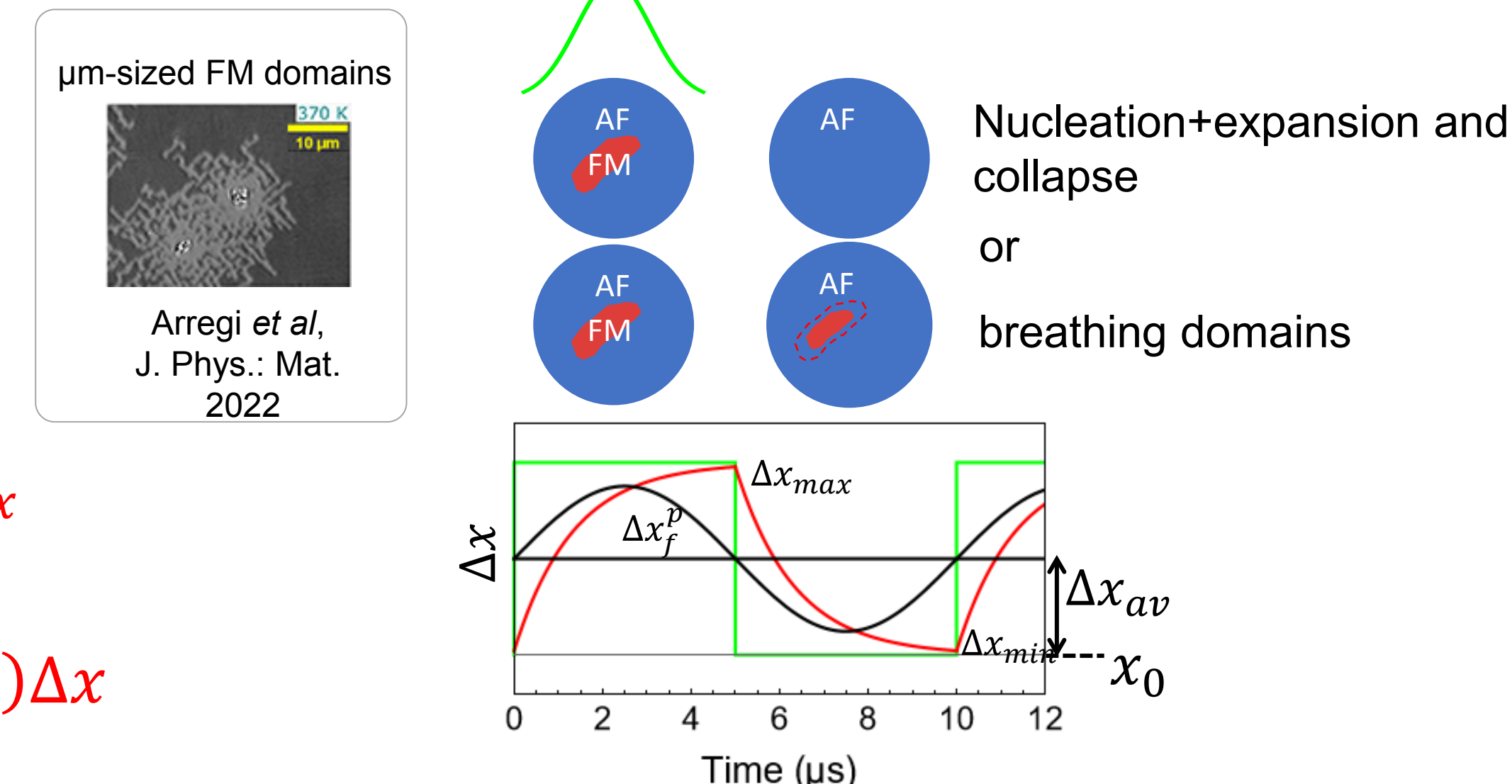
$$R = R_{AF}(1 - x) + R_{FM}x$$

$$x(t) = x_0 + \Delta x(t)$$

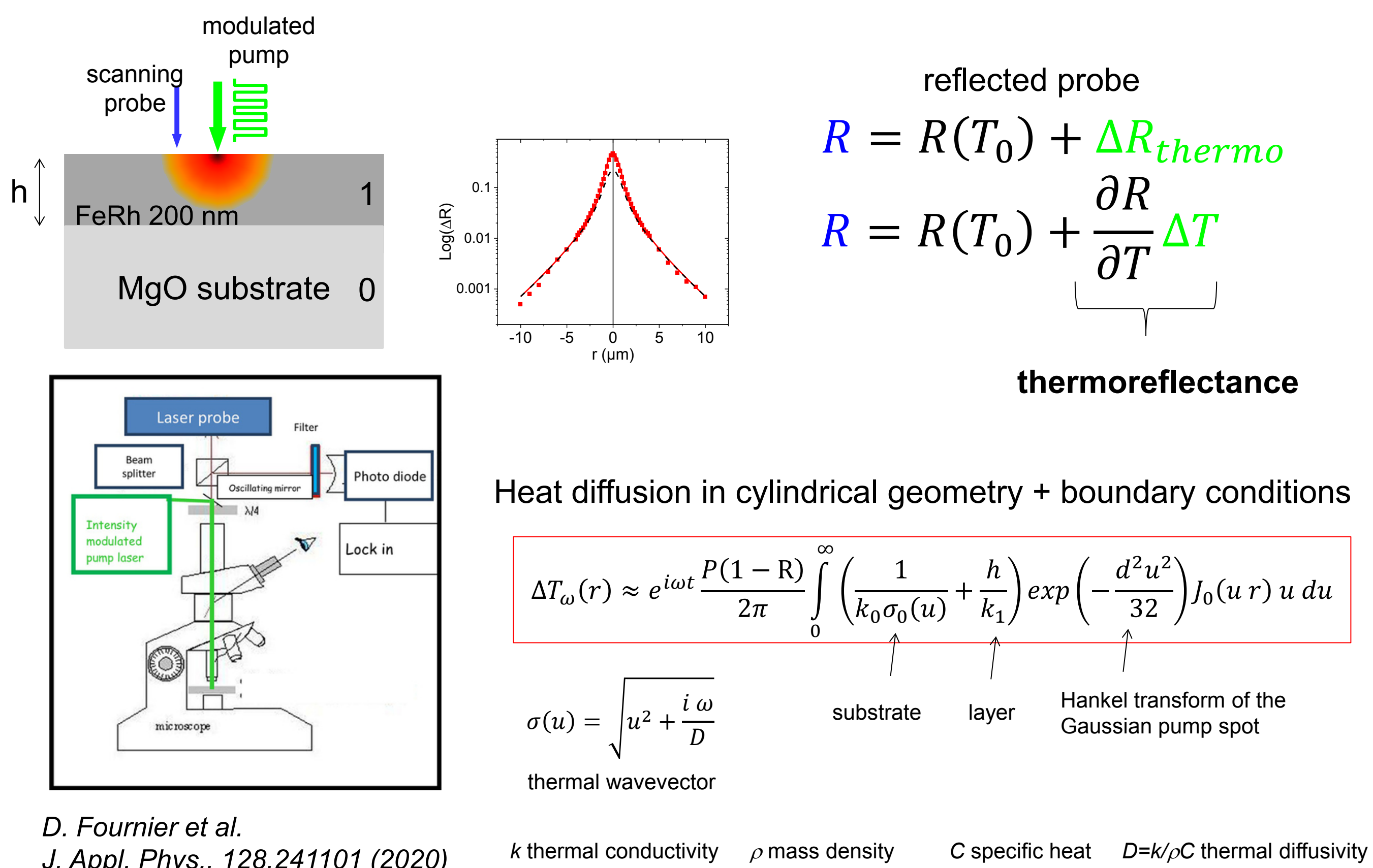
$$R = R(T_0) + \Delta R_{thermo} + \Delta R_x$$

$$\Delta R_x = \frac{dR}{dx} \Delta x = (-R_{AF} + R_{FM}) \Delta x$$

$$x_{av} = x_0 + \Delta x_{av}$$

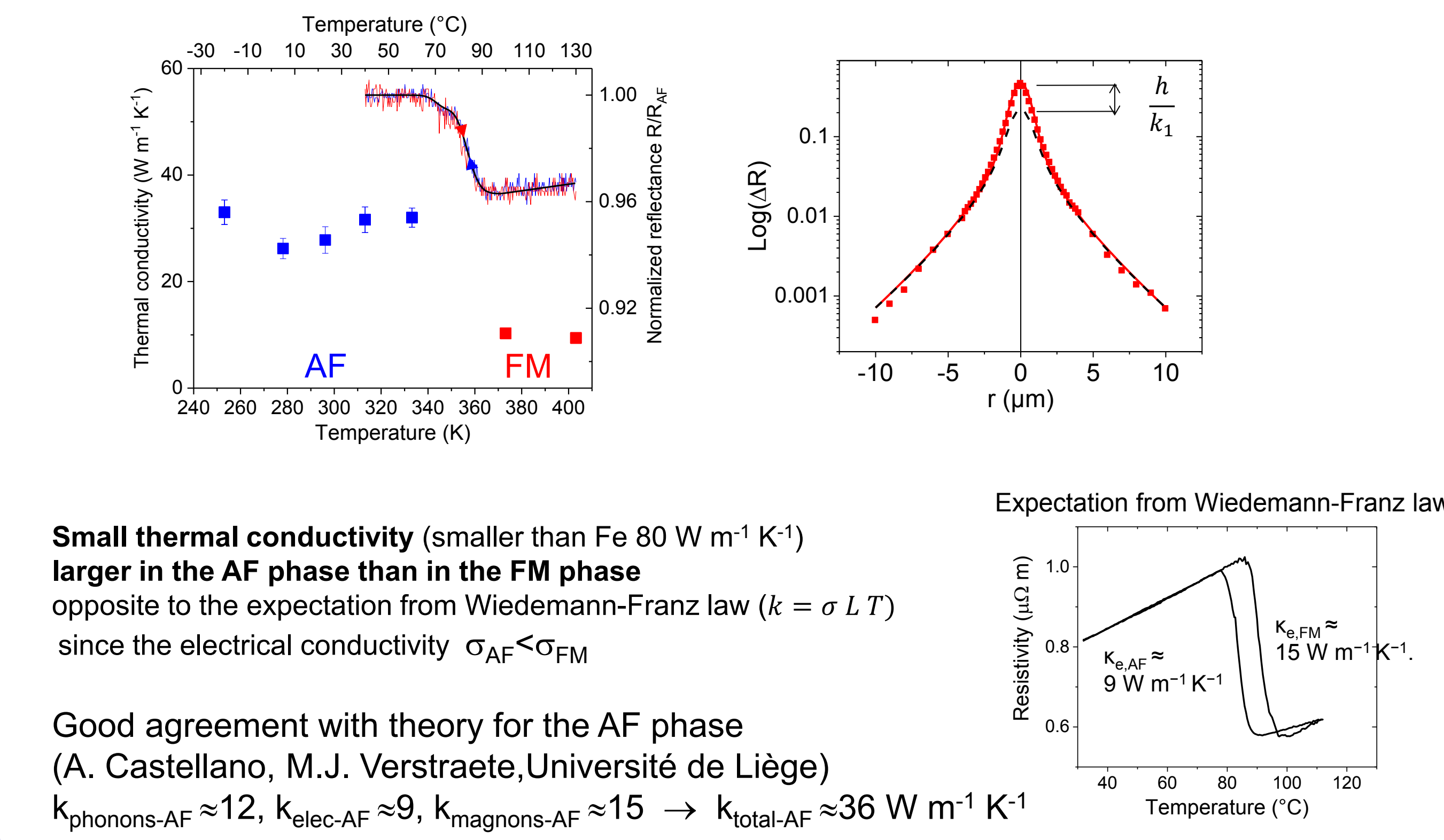


## 2 Modulated reflectance



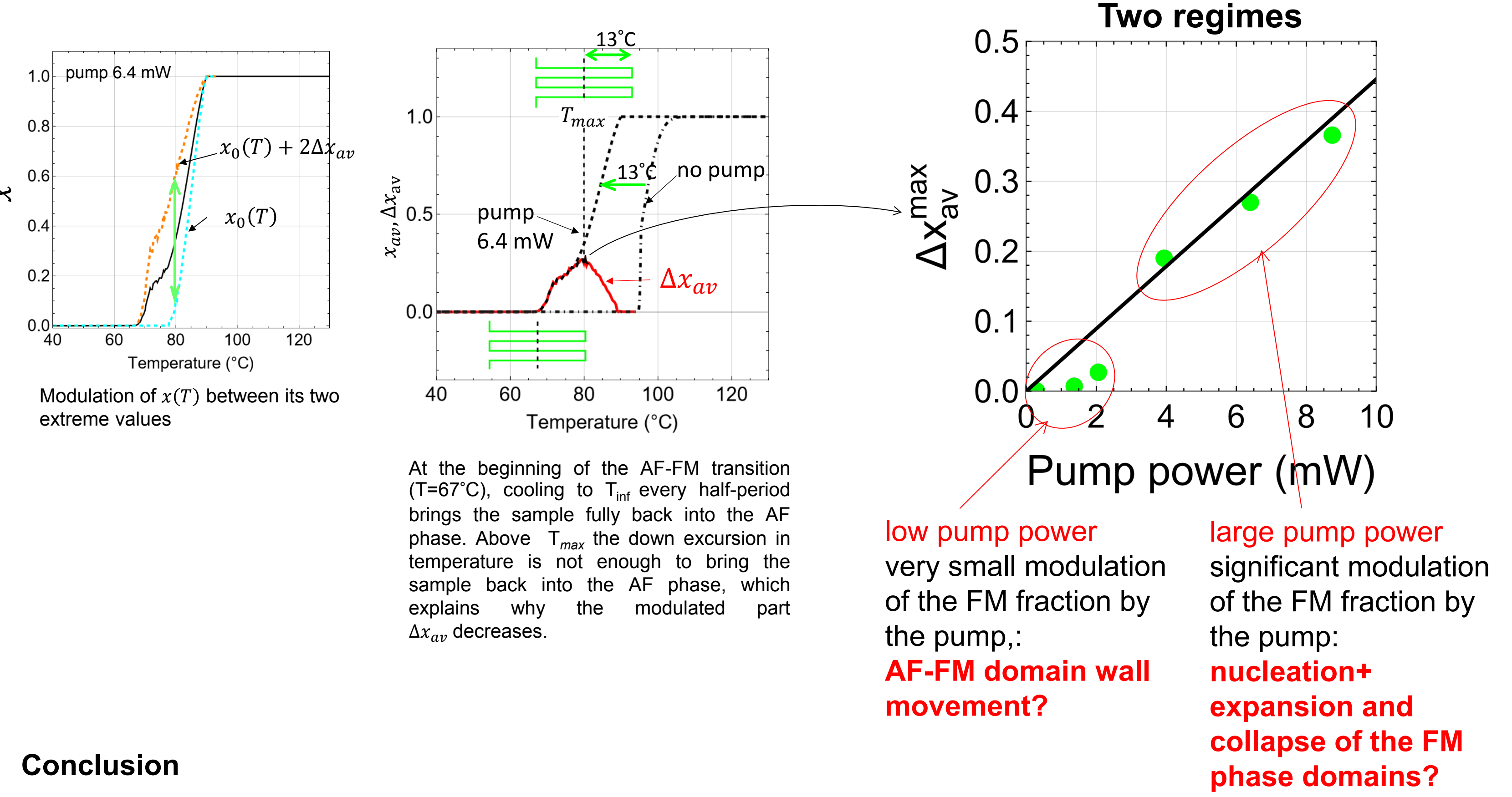
D. Fournier et al. *J. Appl. Phys.*, 128, 241101 (2020)

## 3 Thermal conductivity in AF and FM phases



Small thermal conductivity (smaller than Fe 80 W m<sup>-1</sup> K<sup>-1</sup>)  
larger in the AF phase than in the FM phase  
opposite to the expectation from Wiedemann-Franz law (k = σ L T)  
since the electrical conductivity σ<sub>AF</sub> < σ<sub>FM</sub>

Good agreement with theory for the AF phase  
(A. Castellano, M.J. Verstraete, Université de Liège)  
k<sub>phonons-AF</sub> ≈ 12, k<sub>elec-AF</sub> ≈ 9, k<sub>magnons-AF</sub> ≈ 15 → k<sub>total-AF</sub> ≈ 36 W m<sup>-1</sup> K<sup>-1</sup>



### Conclusion

Thanks to a pretty large reflectivity difference between the AF and FM phases of FeRh (4%), a laser-induced modulation of the FM fraction can be detected in the mixed AF-FM phase. At low pump power, it likely originates from AF-FM domain wall back and forth movement and at large pump power from nucleation+expansion and collapse of FM domains. We can follow the (nucleation+expansion)/collapse process across the transition. Given the risetime of the nucleation+expansion process (2-5 μs, not shown here) the domain growth process is likely governed by AF-FM domain wall velocity. The collapse is complete as long as the pump-off temperature allows to reach the fully AF phase.