Scanning NV center thermometry

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Mathieu Munsch, Patrick Maletinsky, Jean-Baptiste Jager,
Jean-Michel Gérard, Vincent Jacques, Aurore Finco, Isabelle Robert-Philip

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Qnami
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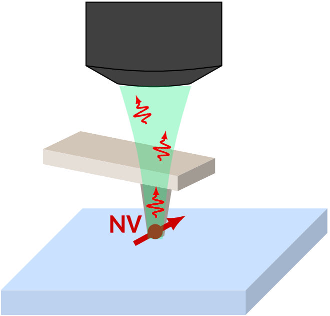
Universität Basel

DPG Spring meeting, March 17th 2025, Regensburg

slides available at https://magimag.eu

Scanning NV center microscopy



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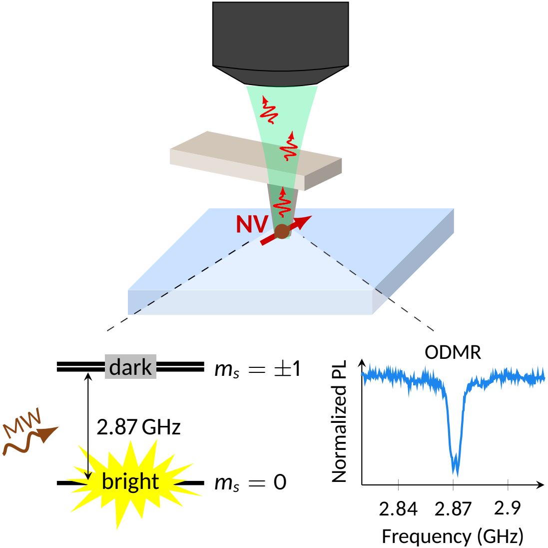

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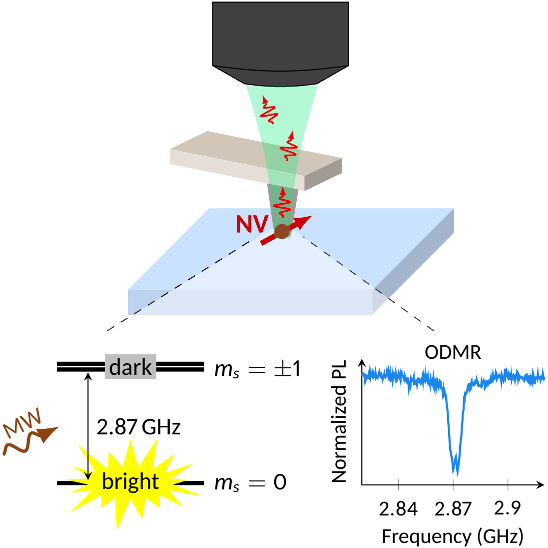
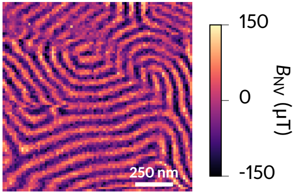
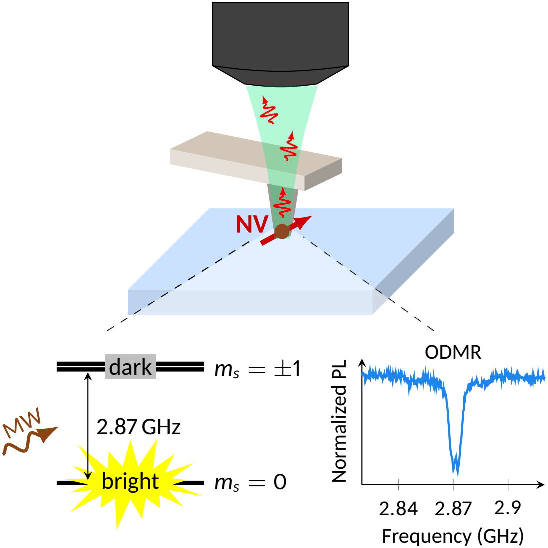


Map magnetic stray field (Zeeman shift)



A. Finco *et al.* *PRL* 128 (2022), 187201

Scanning NV center microscopy



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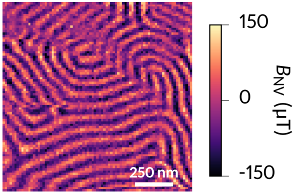

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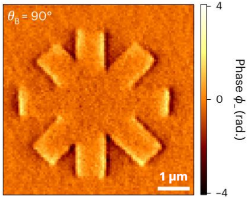
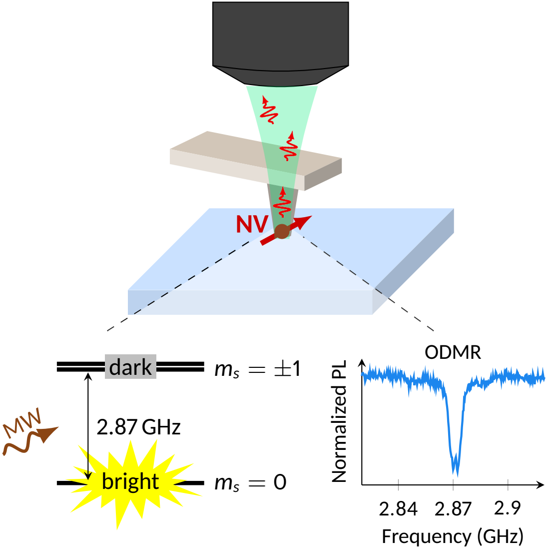
Map electric stray field (Stark shift)



W. S. Huxter *et al.* *Nat. Phys.* 19 (2023), 644

Scanning NV center microscopy



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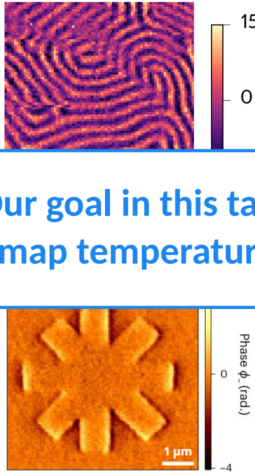

Our goal in this talk: map temperature

W. S. Huxter *et al.* *Nat. Phys.* 19 (2023), 644

Motivations

Nanoscale spatial resolution + operation under ambient conditions

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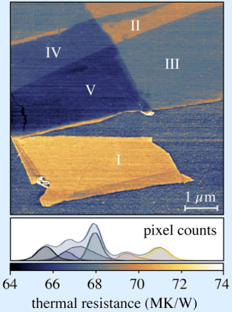
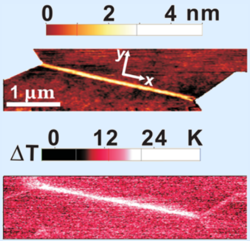
Thermal resistance of graphene flakes (in vacuum)



F. Menges *et al.* *PRL* 111 (2013), 205901

Joule heating in graphene nanoribbons (in N_2 atmosphere)



Y.-J. Yu *et al.* *APL* 99 (2011), 183105

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Measured with SThM

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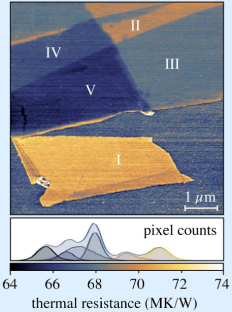

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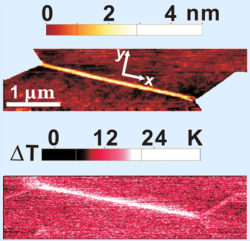

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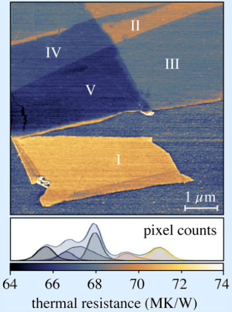

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Joule heating in
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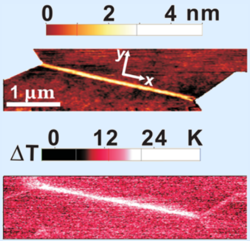
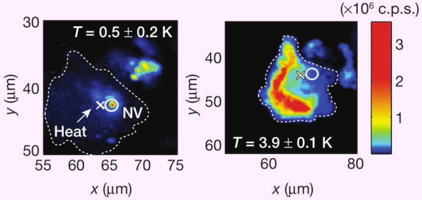


Y.-J. Yu *et al.* APL 99 (2011), 183105

Monitoring of the killing
of cells with temperature



G. Kucsko *et al.* Nature 500 (2013), 54

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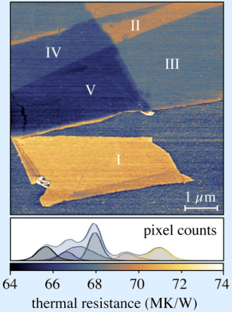

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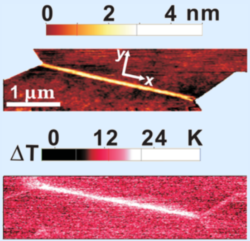
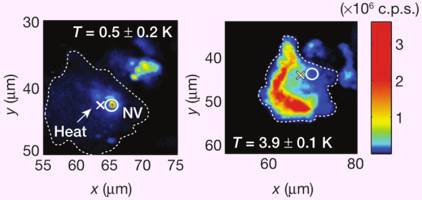


Y.-J. Yu *et al.* APL 99 (2011), 183105

Measured with NV centers in nanodiamonds

Monitoring of the killing of cells with temperature



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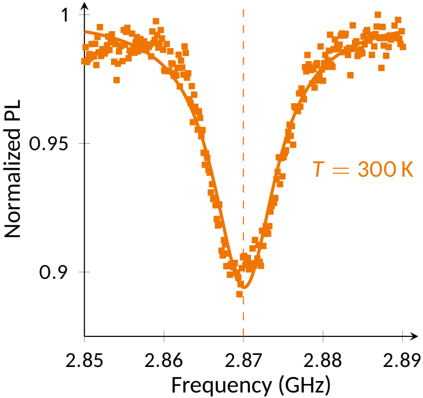
How do we measure T with an NV center?

Thermal crystal dilatation leads to a **shift of the magnetic resonance**



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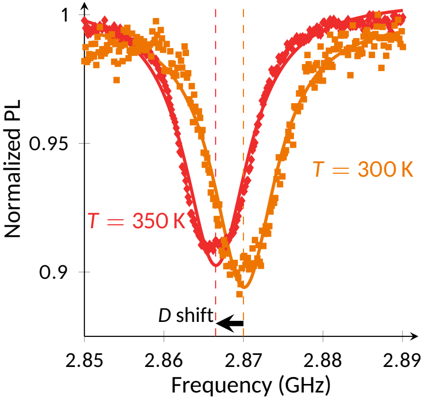

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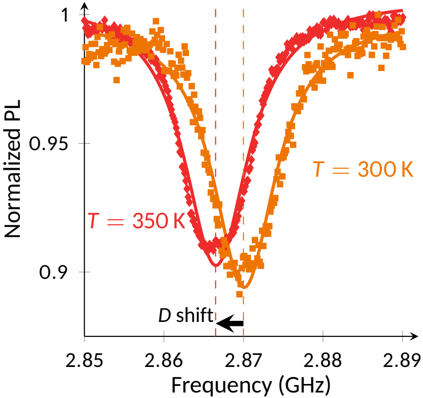

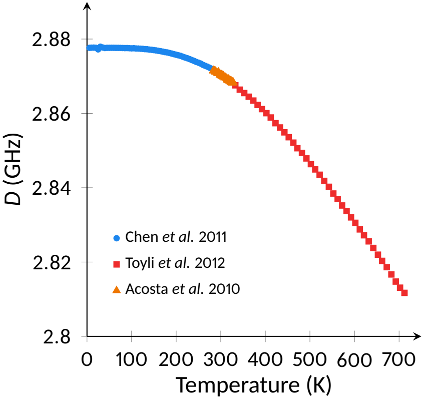

X.-D. Chen *et al.* *APL* 99 (2011), 161903
V. M. Acosta *et al.* *PRL* 104 (2010), 070801
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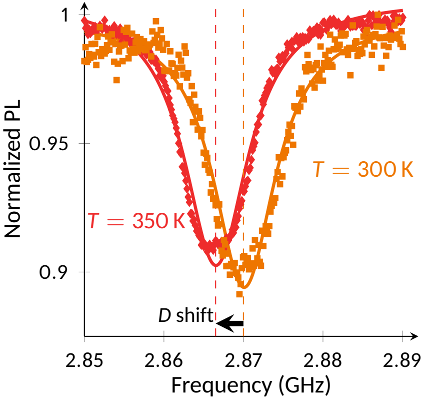

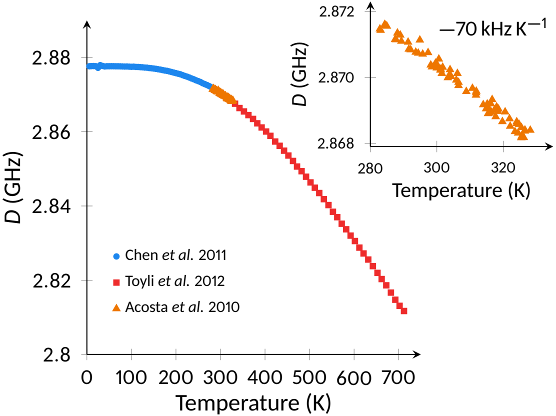

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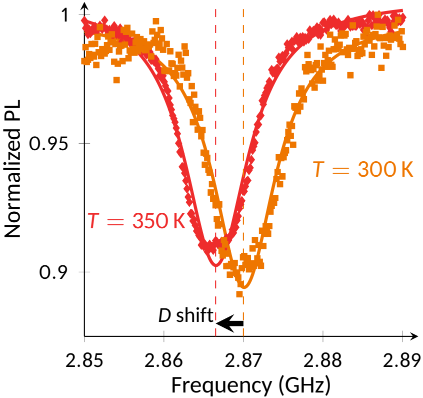

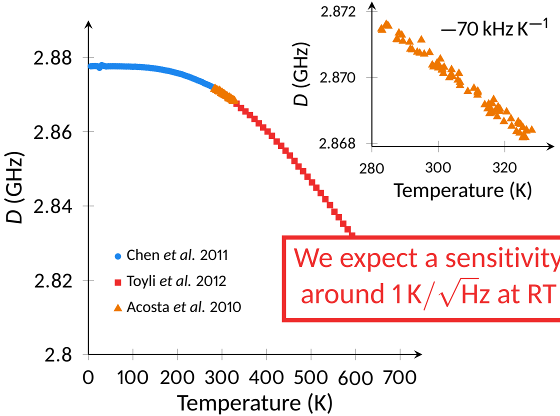

We expect a sensitivity around $1\,\mathrm{K}/\sqrt{\mathrm{Hz}}$ at RT

X.-D. Chen *et al.* *APL* 99 (2011), 161903
V. M. Acosta *et al.* *PRL* 104 (2010), 070801
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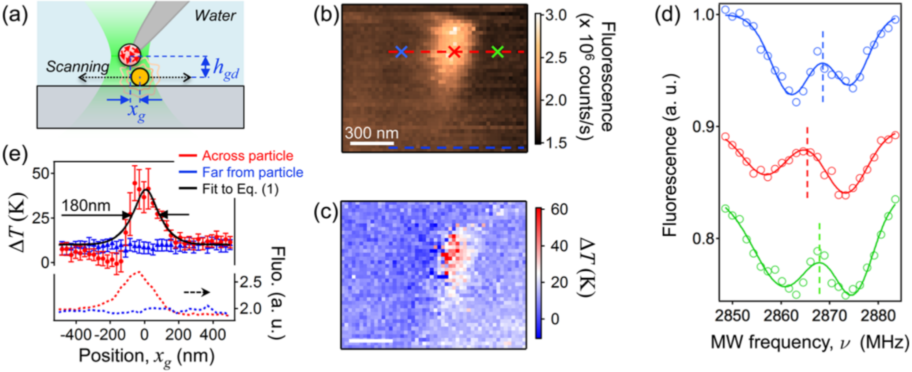
In the literature

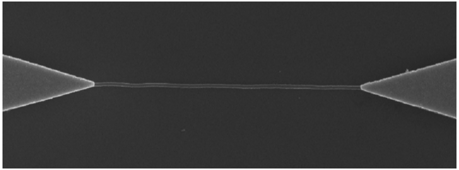
- Photoheated gold nanoparticle
- Experiment using an ensemble of NV centers and scanning in water



J.-P. Tetienne *et al.* *Nano Lett.* 16 (2016), 326

Our samples

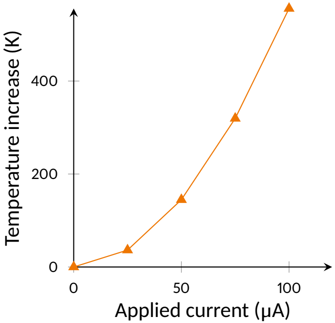
Doped Silicon nanowire
Deposited on SiO_2, with gold contacts
Fabricated at Pheliqs in Grenoble



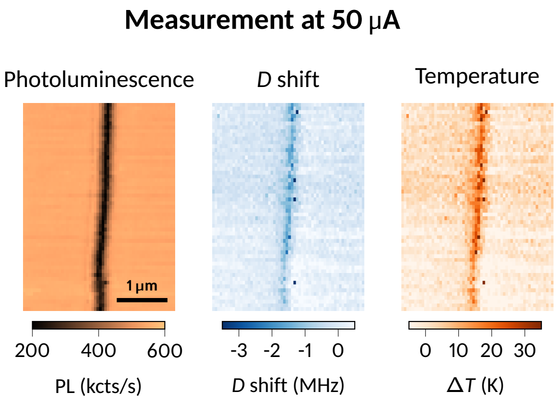
Nanowire width: 100 to 150 nm

We expect a strong **Joule heating** at the nanowire when applying current

Comsol simulation

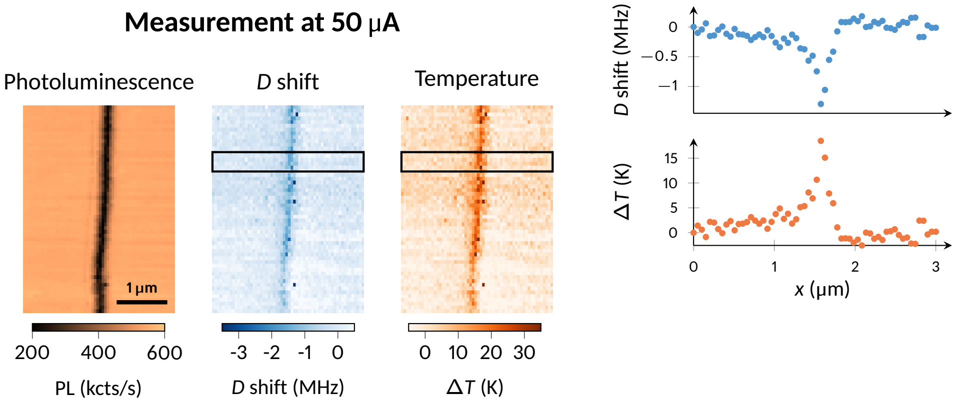


A first temperature map



A first temperature map

Measurement at 50 µA



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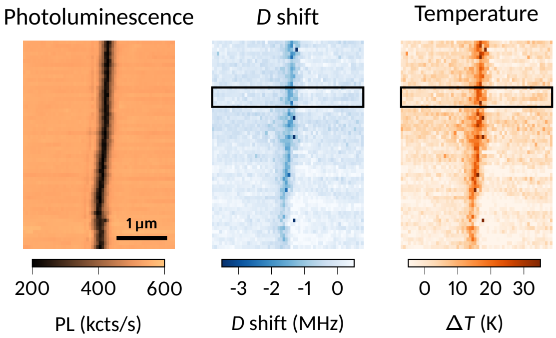

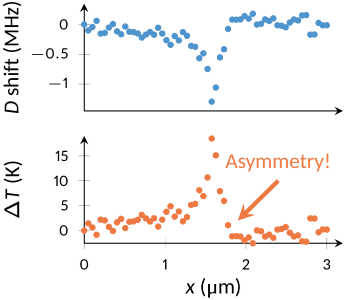

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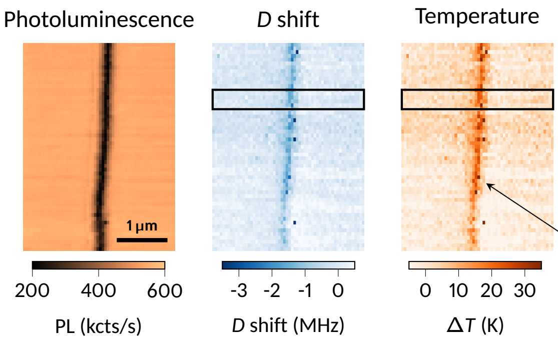
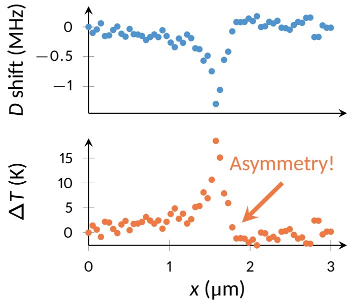
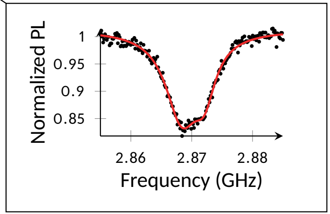


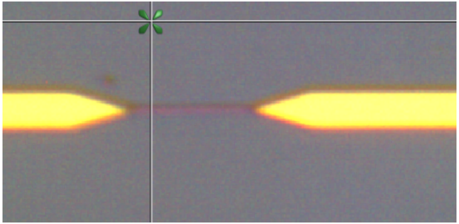




- Oersted field from the wire
- The temperature increase is too small!

The terrible fate of the samples

The nanowire **before**
we start measuring



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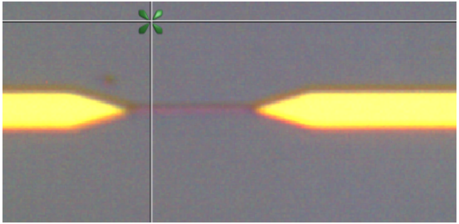
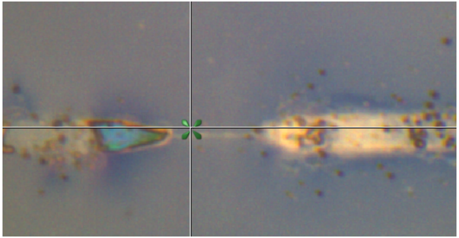
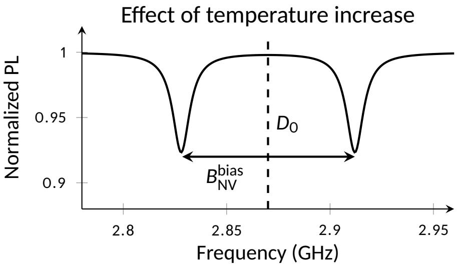


The nanowire **after**
we worked on it for some time
(usually not very long)



Measurement under external magnetic field



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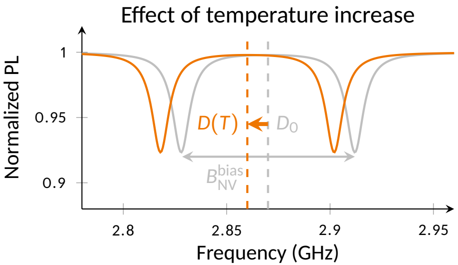

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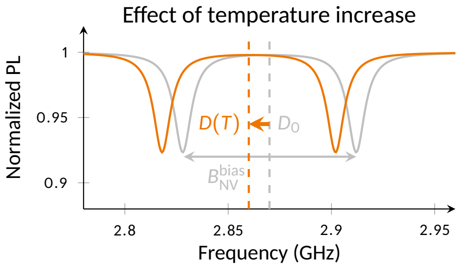

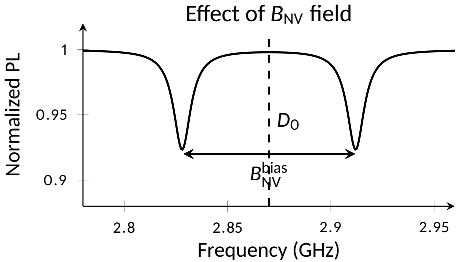

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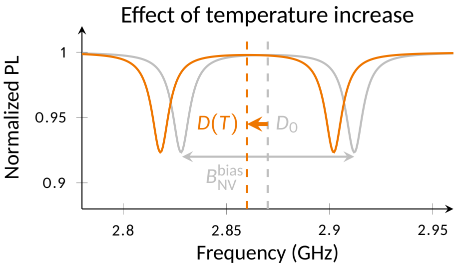

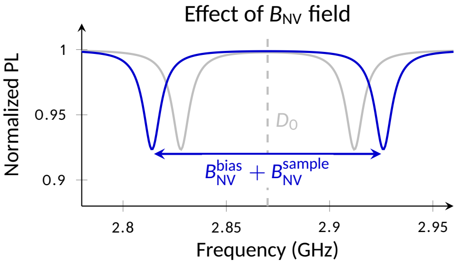

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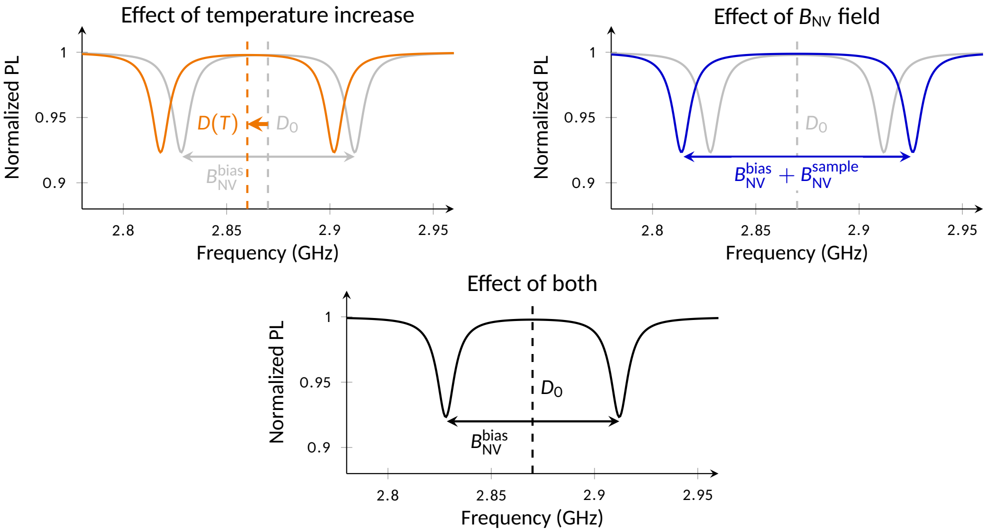

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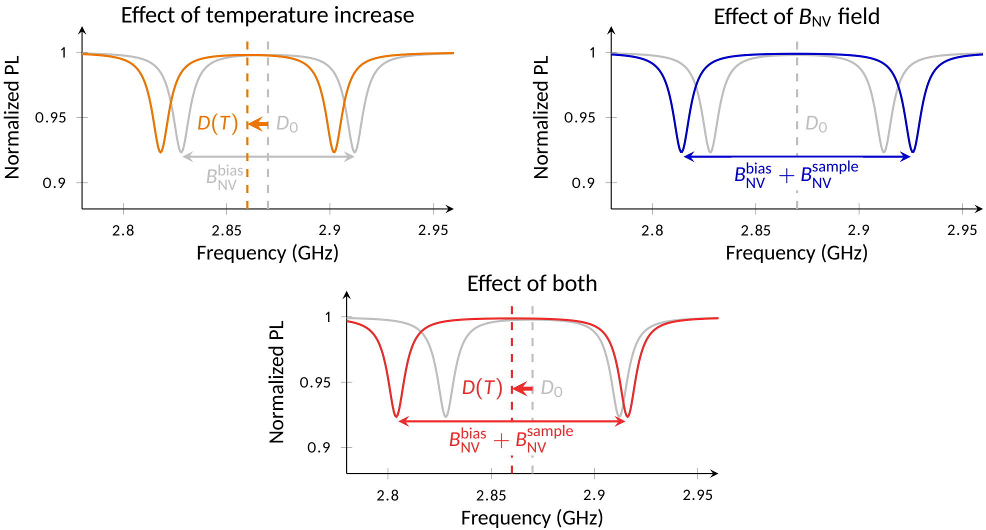
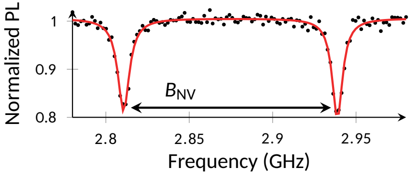
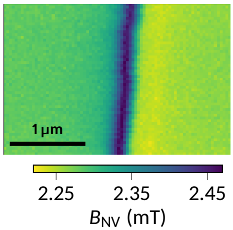


A second temperature map

Measurement at 100 μA, under an out-of-plane bias field





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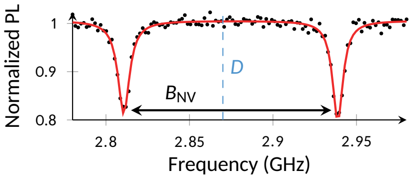

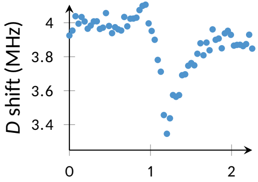

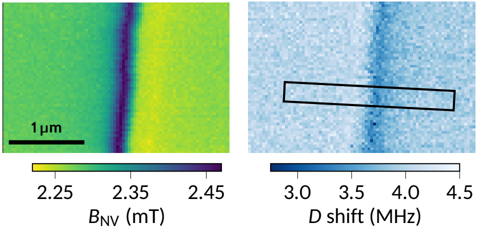

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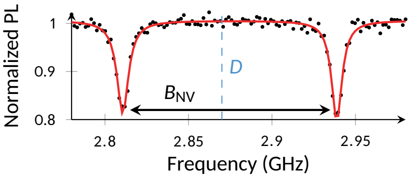
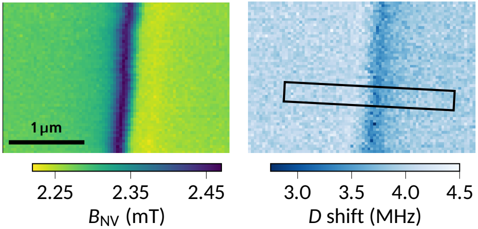
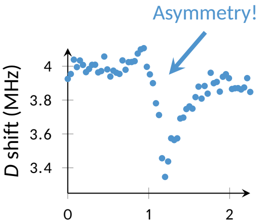
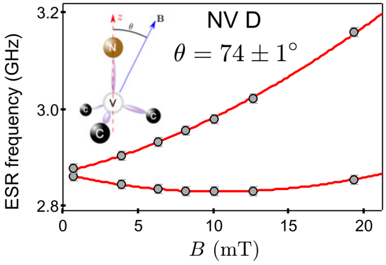




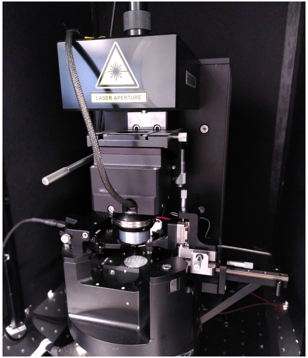


The problem with perpendicular magnetic field

Perpendicular magnetic field also shifts *D*, and looks like an effective cooling!



J.-P. Tetienne *et al*. *New Journal of Phys*. 14 (2012), 103033



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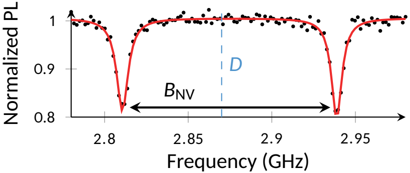

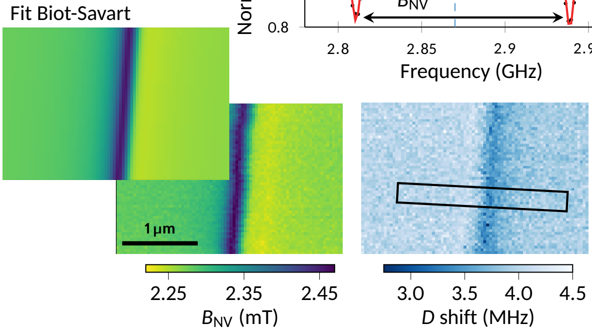

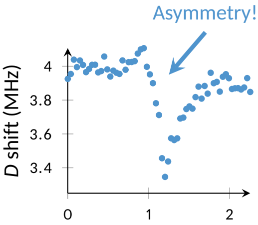

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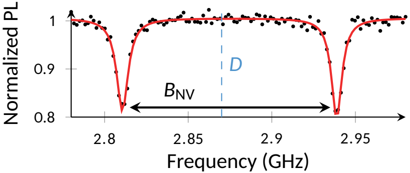
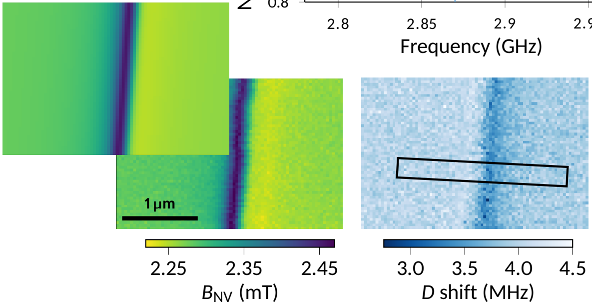
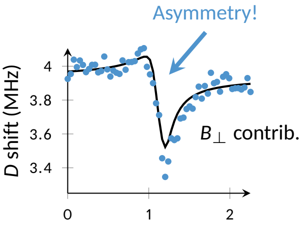


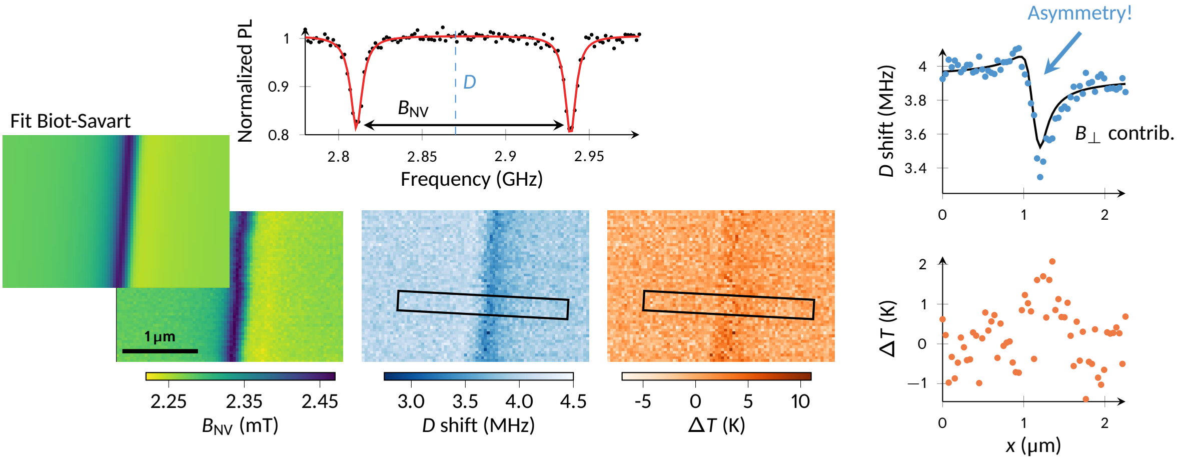
Fit Biot-Savart





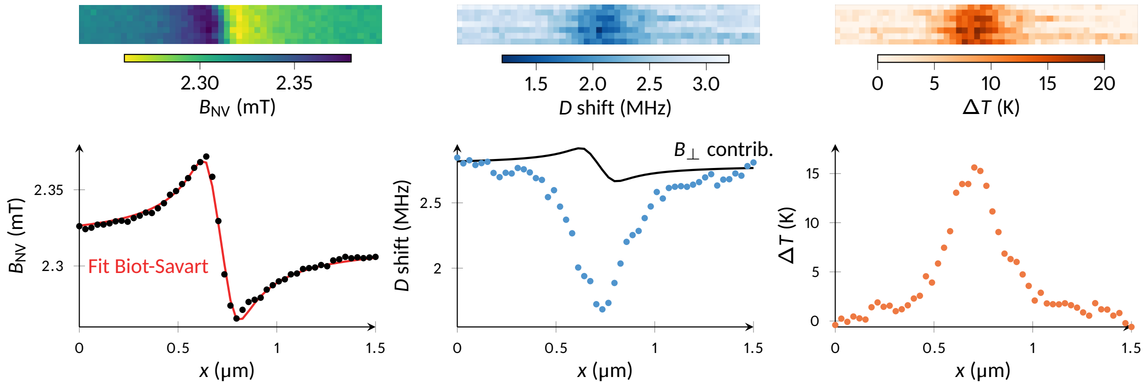
A second temperature map

Measurement at 100 μA, under an out-of-plane bias field



A third temperature map

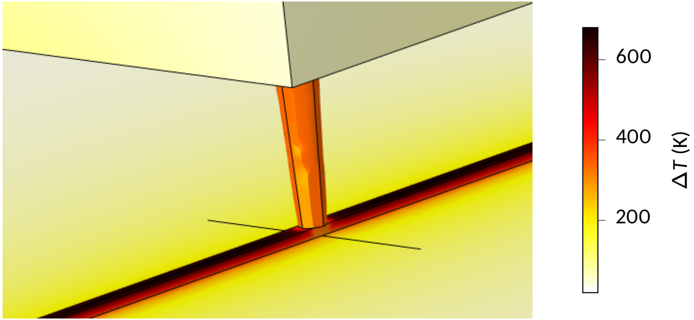
Different nanowire, current 60 μA, different diamond probe



This time we observe Joule heating, but again smaller than expected...

Identified issues

- The contact between the apex of the diamond tip and the sample is not controlled
- Diamond has a very large thermal conductivity (1000 to 3300 $\mathrm{W\,m^{-1}\,K}$) and **dissipates a lot of thermal energy!**



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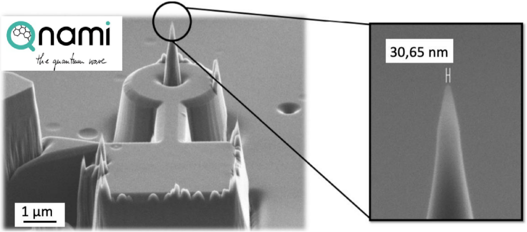
So how could we actually perform scanning NV thermometry?

- **Reduce the volume of diamond** in the probe to minimize dissipation
- Use an **ensemble of NV centers**, same orientation, to increase the signal
- Shift the **NV centers away from the tip apex** to reduce the effect of stray field
- **Conical pillar** to improve spatial resolution



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Interested in joining our team?
PhD and postdoc positions available
in scanning NV microscopy
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