

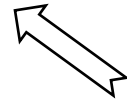
Optical detection of single defects in silicon

Anaïs Dréau

Laboratoire Charles Coulomb, CNRS & Montpellier University, France

Spin defects in semiconductors for quantum technologies

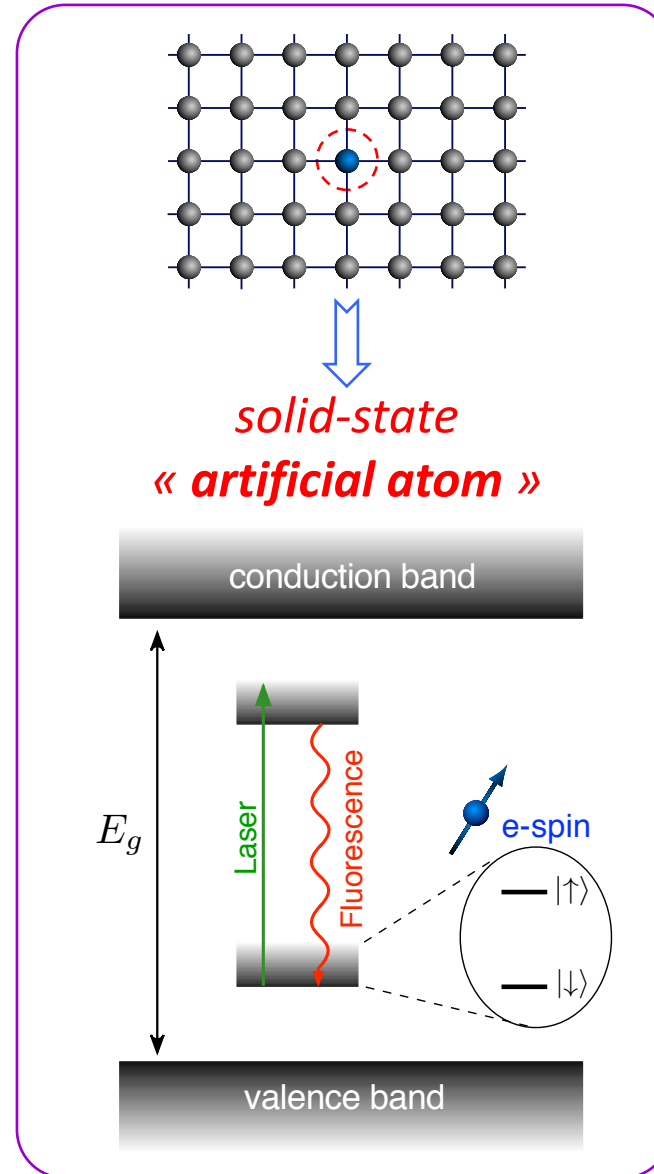
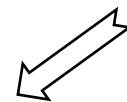
Quantum communication



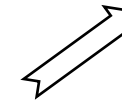
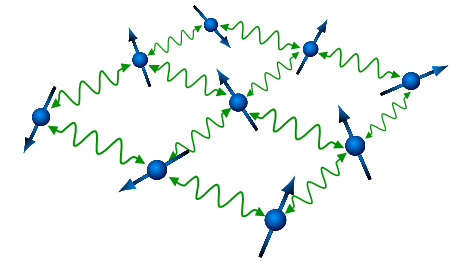
Biology imaging



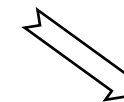
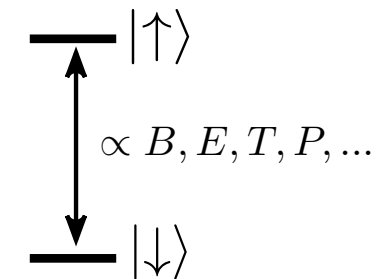
Mohan et al., *Nano Lett.* 10 (2010)



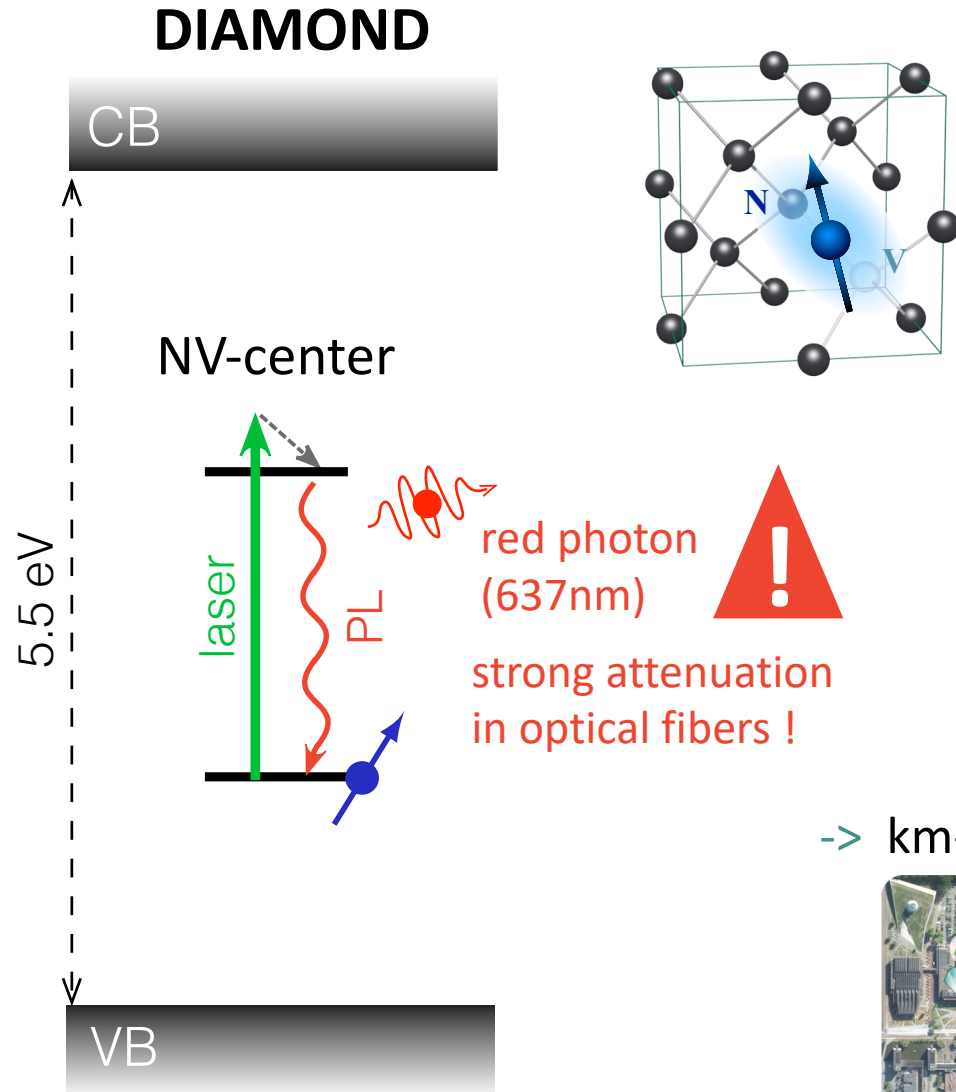
Quantum information



Sensing



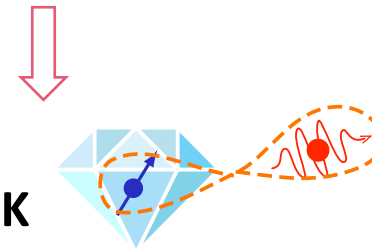
The Nitrogen-Vacancy center in diamond



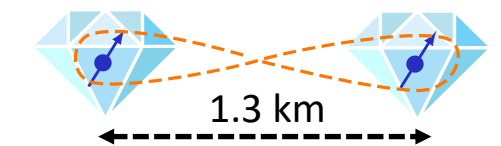
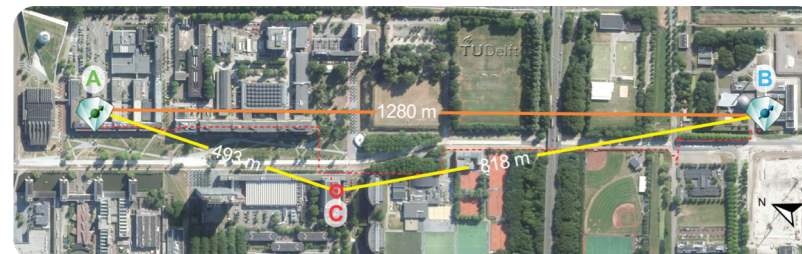
➤ 1st isolation of single NV-centers in 1997
Gruber et al., *Science* **276** (1997)

- investigated for many quantum applications
- quantum sensing @300K
 - quantum communication networks

spin-photon interface @ 4K



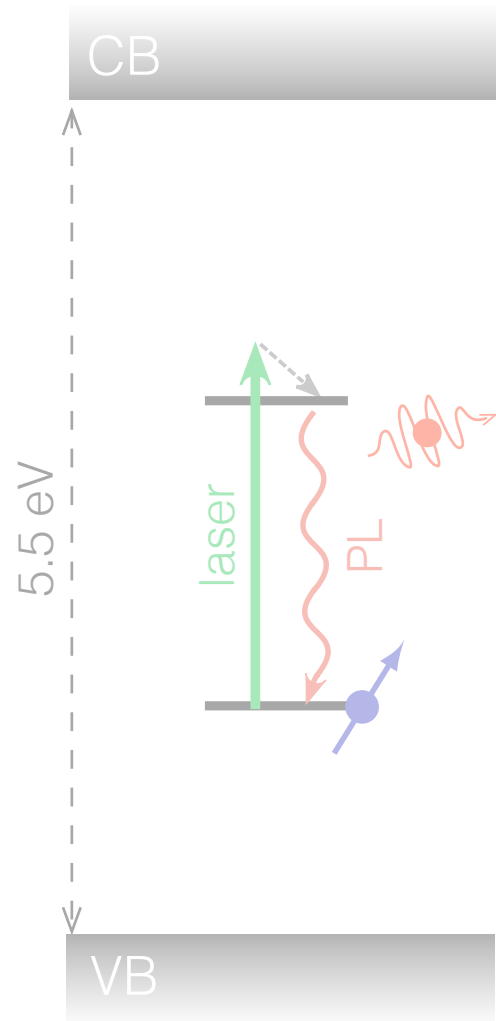
-> km-scale entanglement distribution



Hensen et al., *Nature* **526** (2015)

Exploring other semiconductors

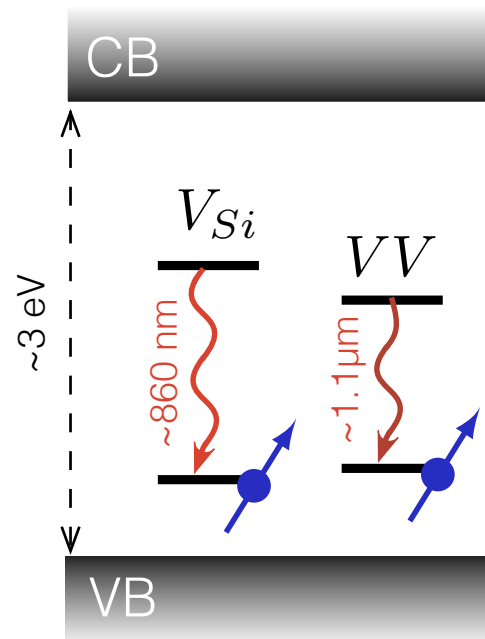
DIAMOND



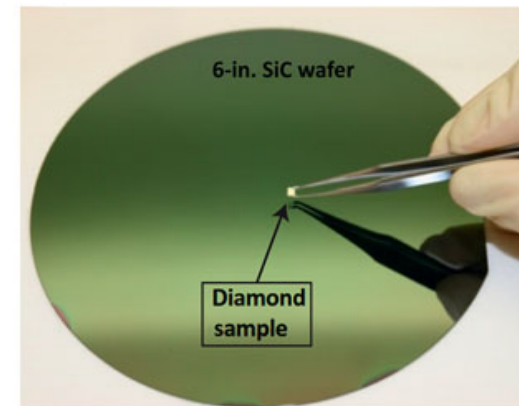
GOALS

- telecom emission
- platform adapted to large scale process

SILICON CARBIDE



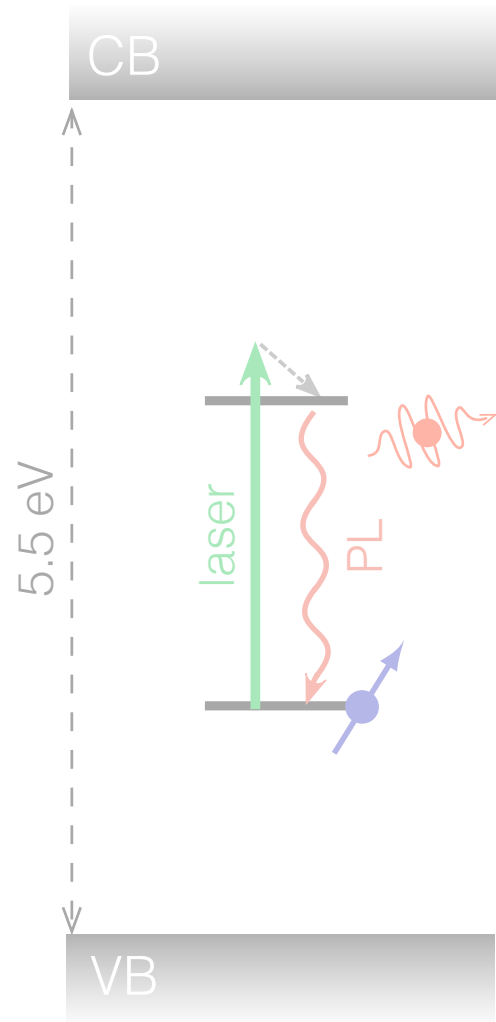
- single spin defects in SiC
Christle et al., *Nat. Mat.* **14** (2015)
Widmann et al., *Nat. Mat.* **14** (2015)



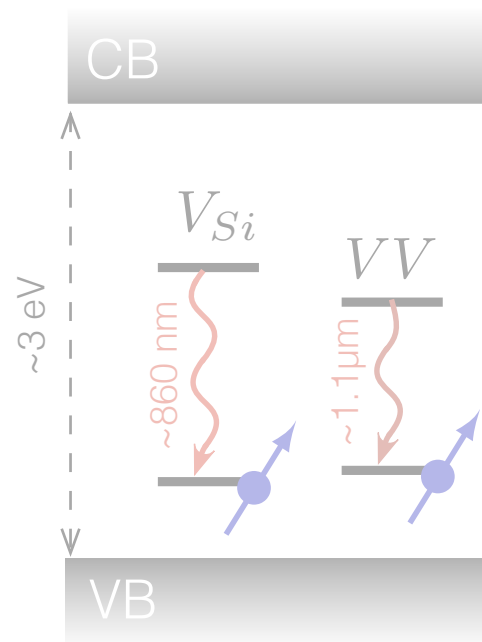
Koehl et al., *MRS Bull.* **40** (2015)

And in small bandgap semiconductors ?

DIAMOND

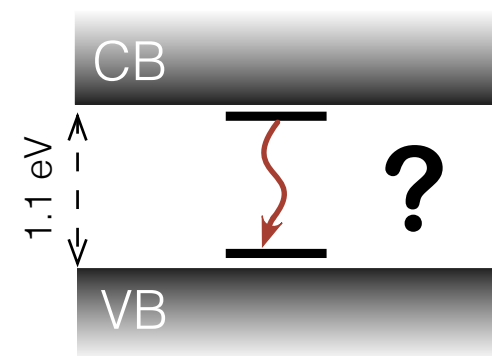


SILICON CARBIDE



Optical isolation
of **single** defects
possible in **silicon** ?

SILICON

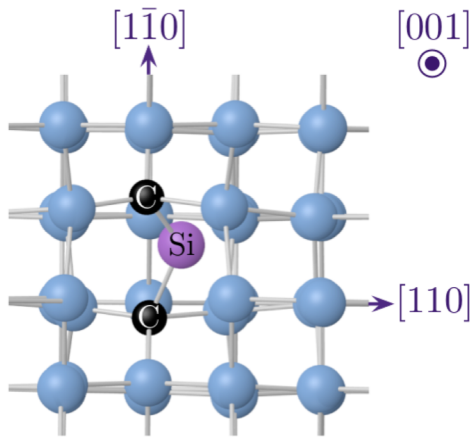
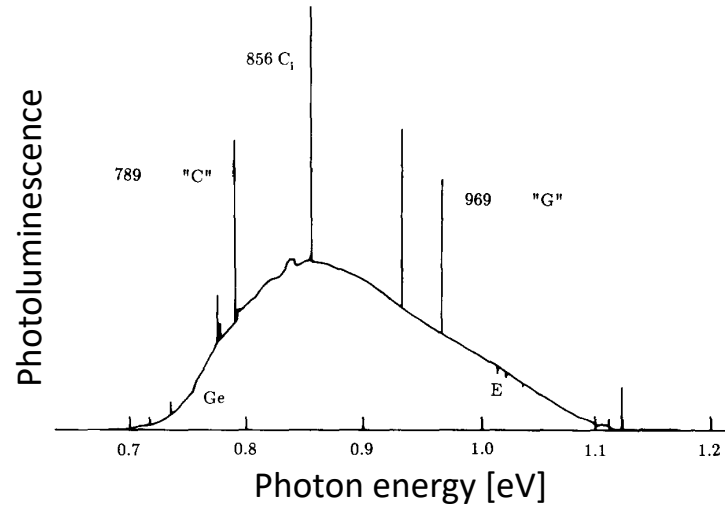


Fluorescent defects in silicon

- > 100 luminescent defects referenced

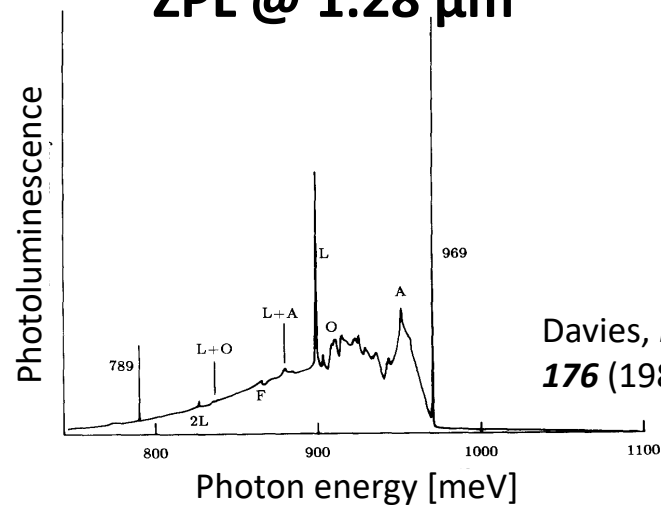
Davies, *Physics reports* **176** (1989)

- the **G-center** in silicon



2 carbons + 1 silicon

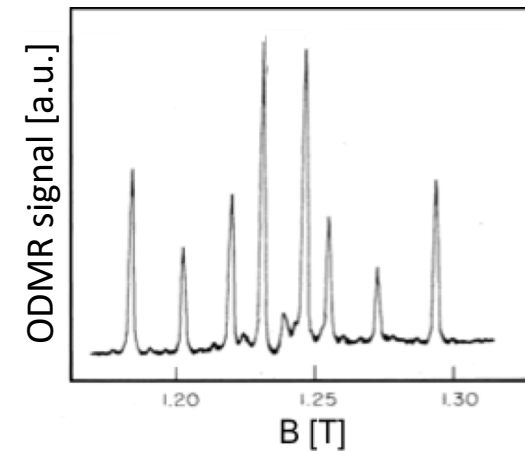
telecom emission
ZPL @ 1.28 μm



Davies, *Phys. rep.* **176** (1989)



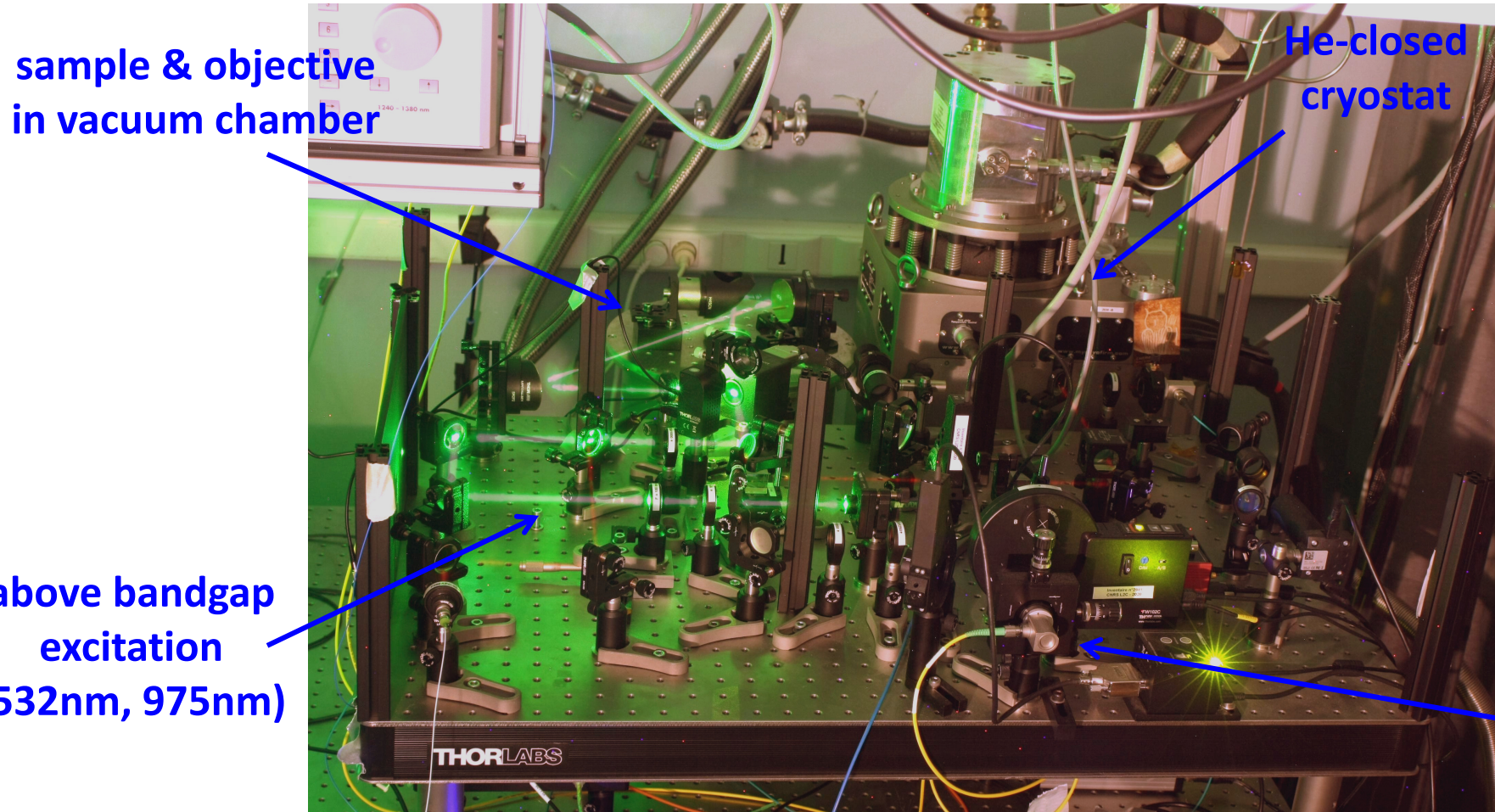
metastable spin triplet
optically detectable



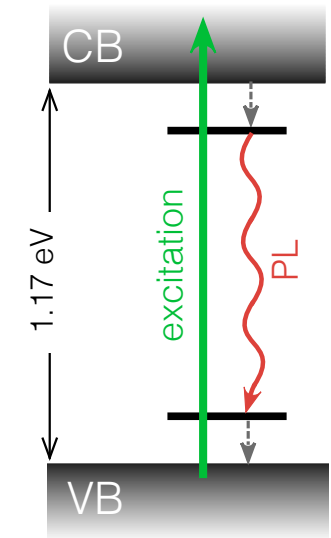
Lee et. al.,
PRL (1982)

Experimental setup

- Low-temperature **confocal** microscope optimized for NIR detection

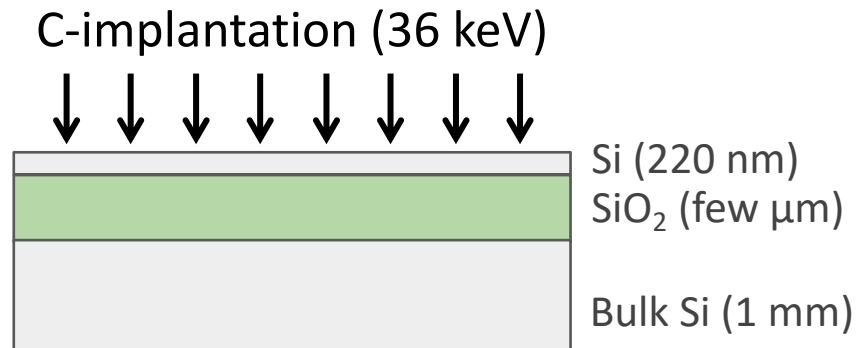


*above gap
optical excitation*



fiber-coupled single-photon detectors

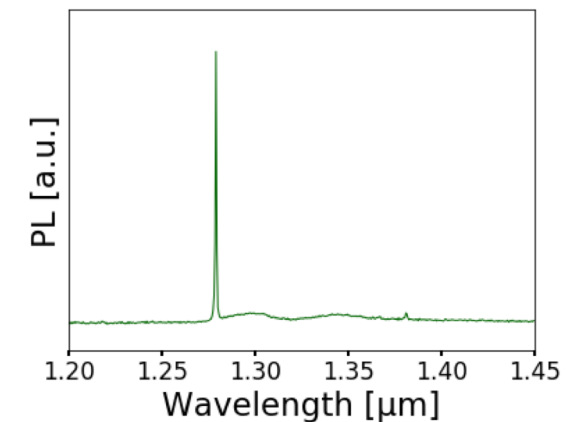
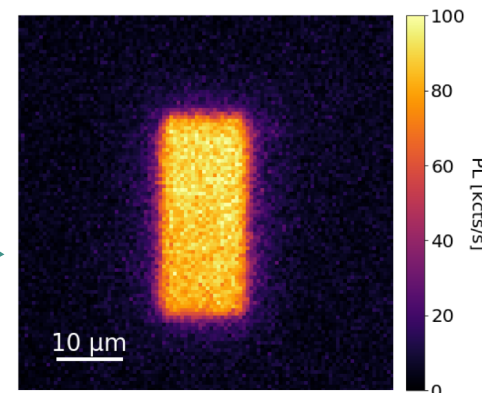
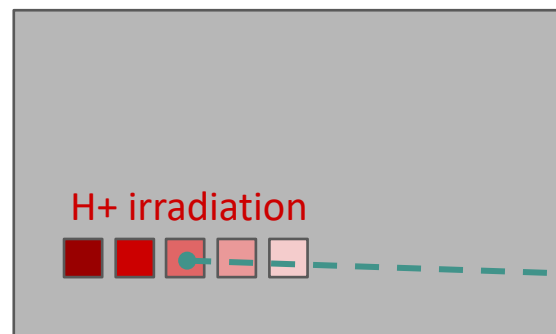
Sample engineering



commercial SOI wafer

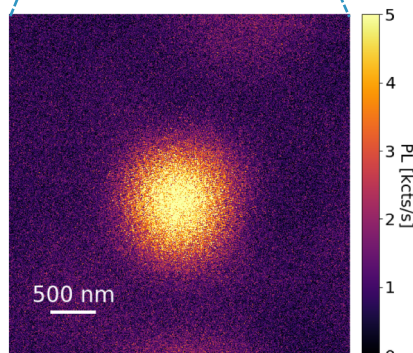
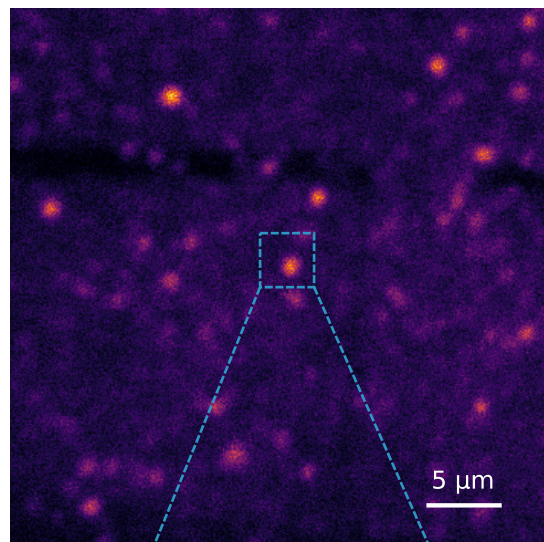
C-implantation at $5 \times 10^{13}/\text{cm}^2$
+
flash annealing (20s @ 1000°C)

➤ C+H => Dense ensembles of G-centers

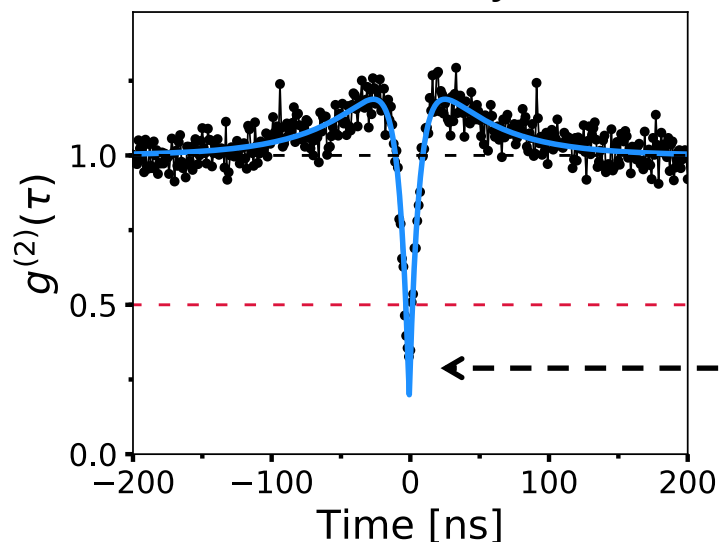


Single G-centers in silicon

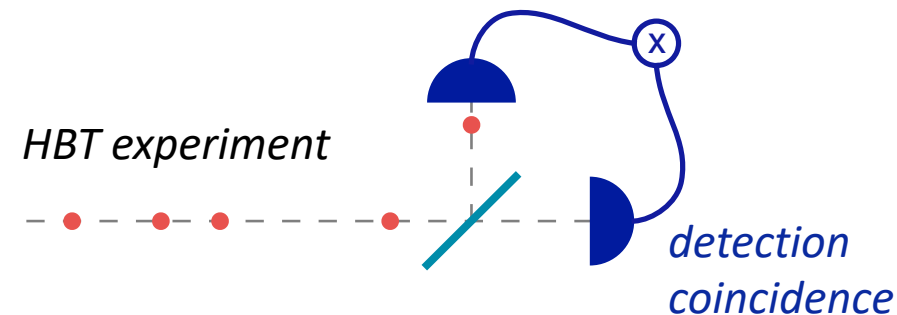
Optical scan at 10 K



autocorrelation function

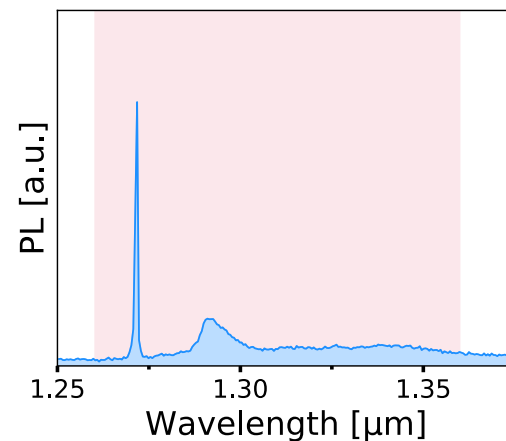


HBT experiment



antibunching $g^{(2)}(0) < 0.5$

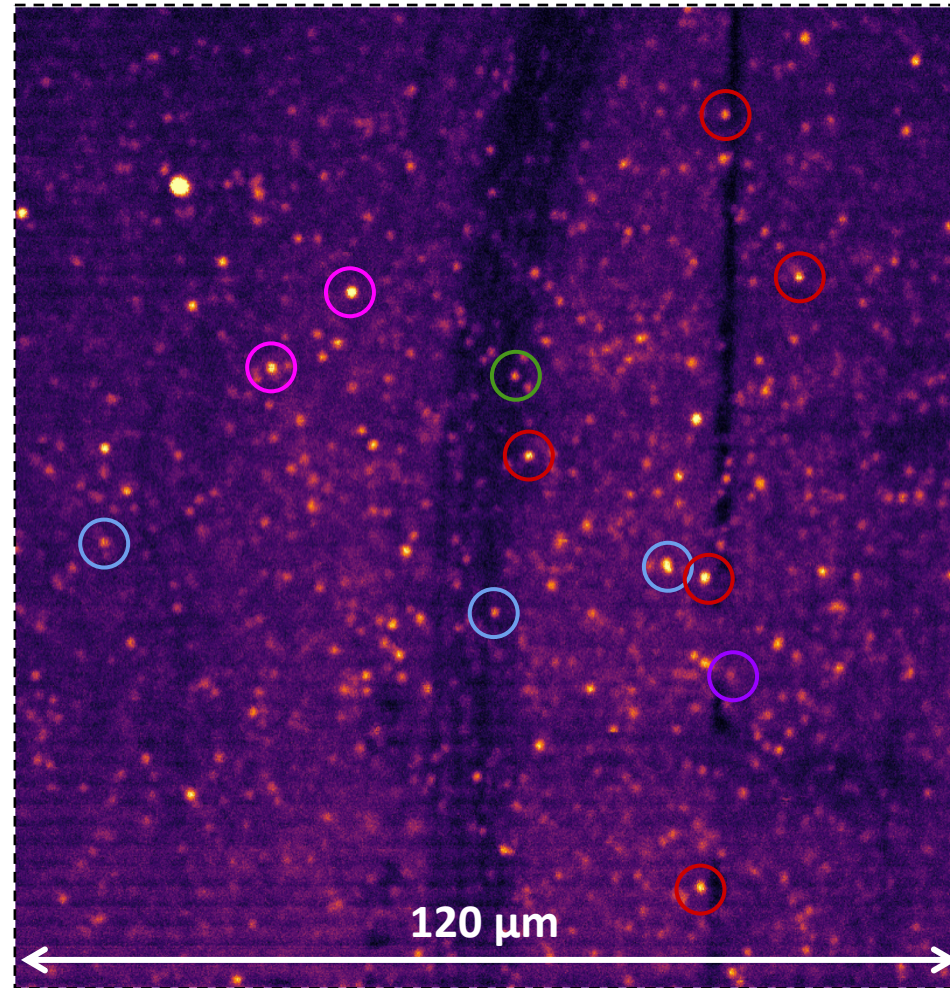
single emitter in silicon



**emission in the
telecom O-band**

Many single defects in silicon...

Optical scan at 10 K

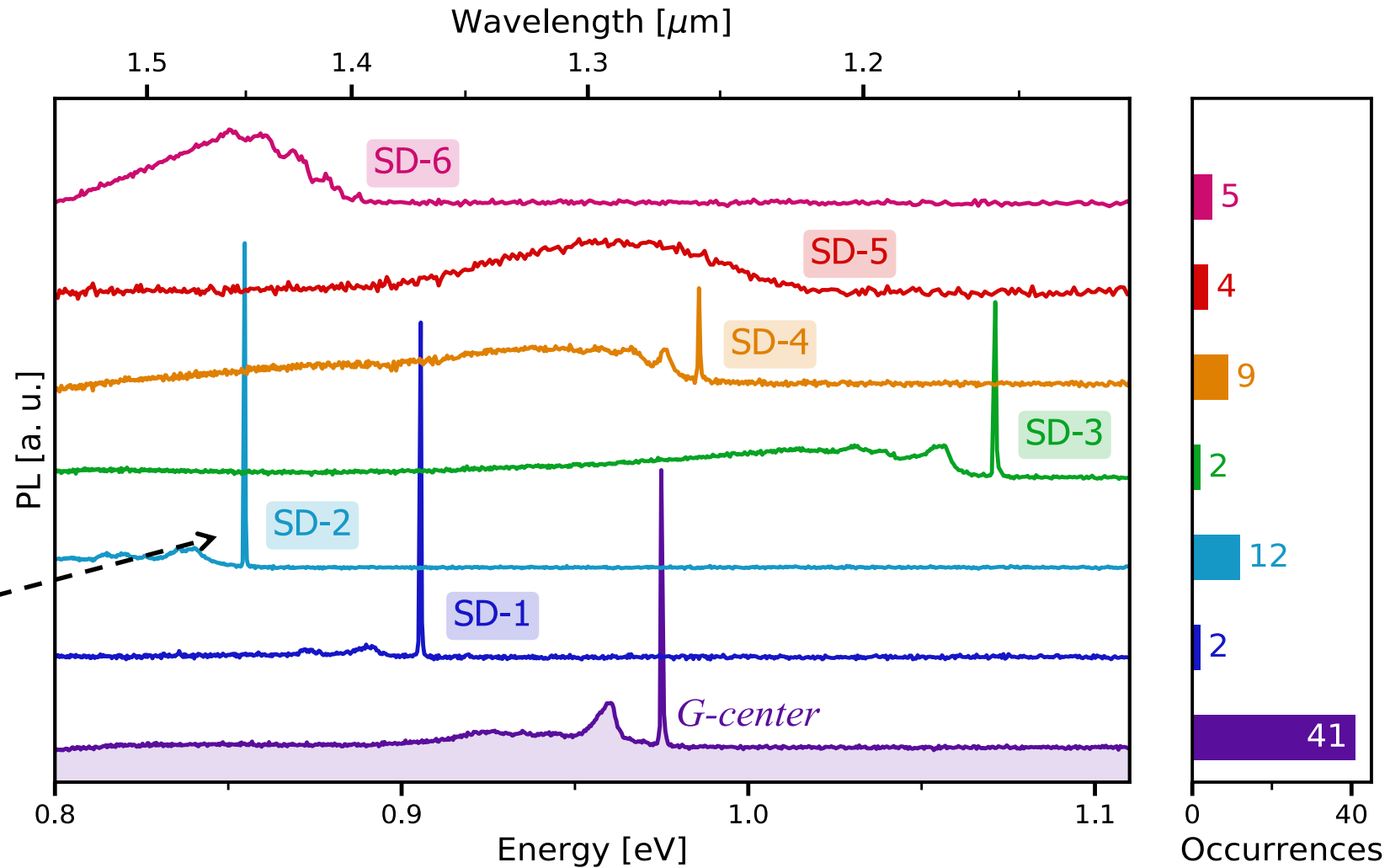


Detecting new fluorescent defects in silicon?

6 new families of single emitters

➤ unidentified defects

interstitial carbon ?



Conclusion

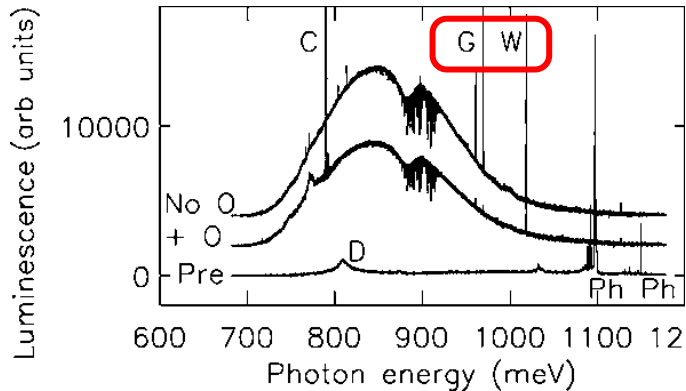
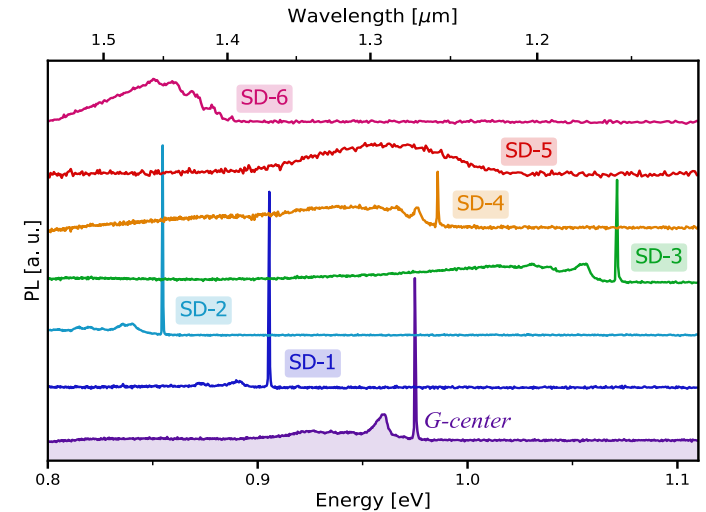
- investigation at single-defect scale
- > new insights into the properties and dynamics of optically-active defects in silicon



G-center SD-1 to SD-6

Wedjem*, Durand* *et al.*,
Nature Electr. **3** (2020)

Durand *et al.*, *PRL* **126** (2021)



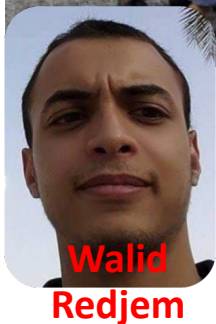
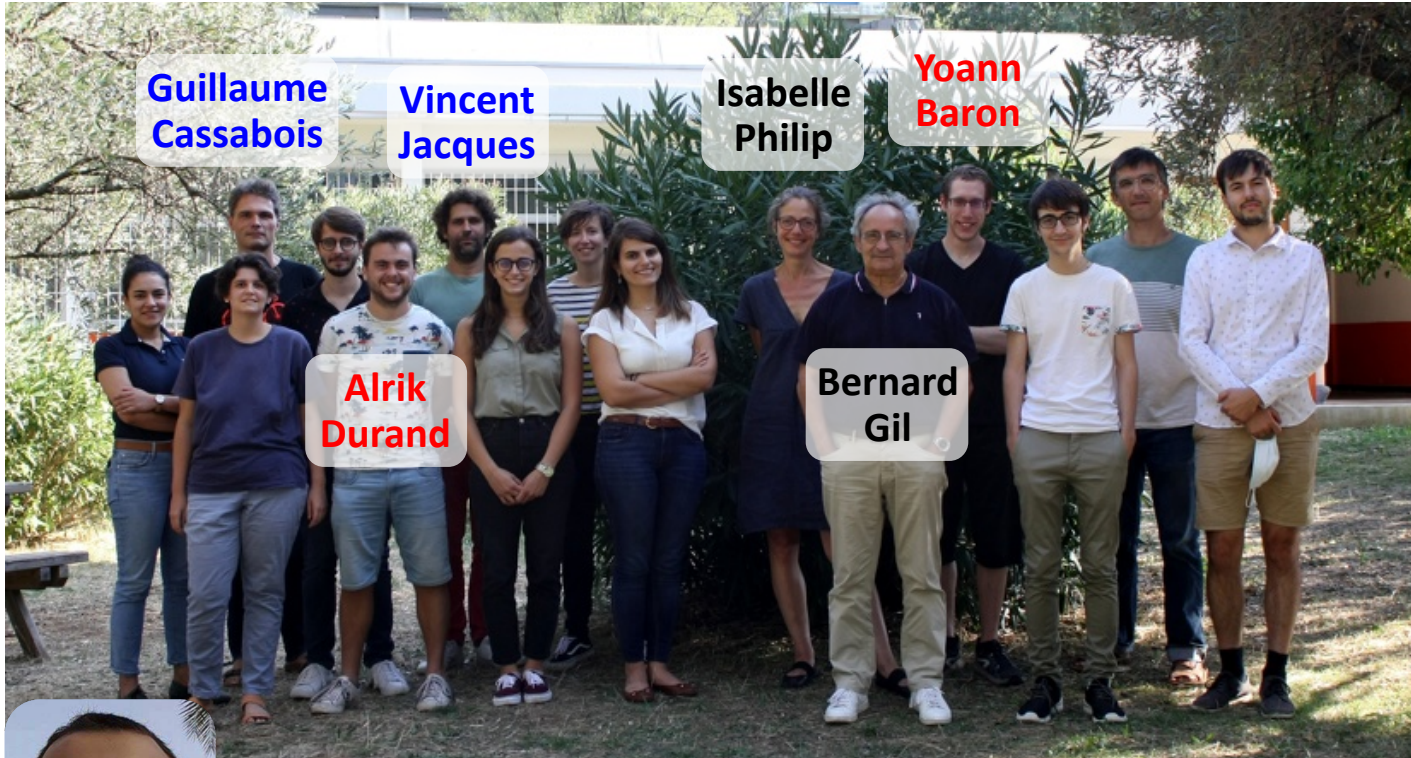
Davies *et al.*, *PRB* **73** (2006)
*Radiation damage in silicon
exposed to high-energy protons*



***optical detection at single-defect scale
useful for high-energy physics
experiments?***

Thank you for your attention!

the Solid-State Quantum Technologies group @L2C Montpellier



Collaborators for silicon projects



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Tobias Herzig
Jan Meijer
Sébastien Pezzagna
Leipzig University (Germany)



Andrej Kuznetsov
Oslo University
(Norway)



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Damien Caliste
Pascal Pochet
Grenoble (FR)



Hai Son Nguyen
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Lyon (FR)



Péter Udvary
Adam Gali
Budapest (Hungary)