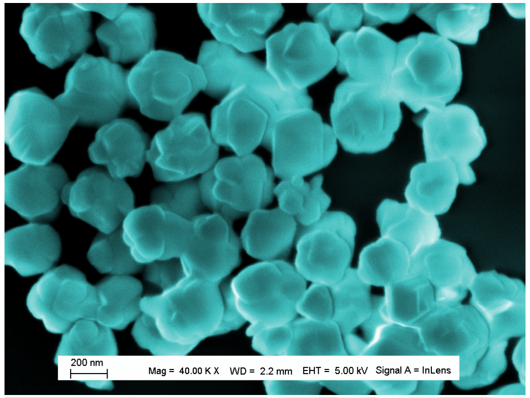
NARROW OPTICAL AND SPIN LINEWIDTHS IN RARE EARTH DOPED MICRO- AND NANO-STRUCTURES



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Paris, France

Physics of Quantum Electronics 2017
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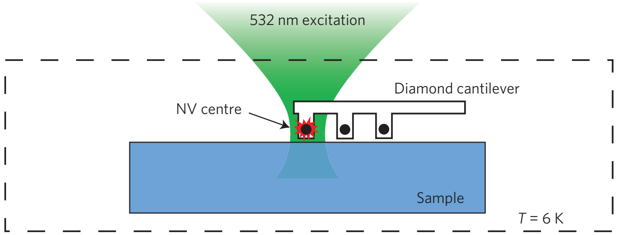
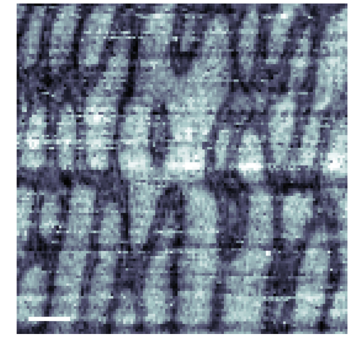
Introduction

- **Quantum technologies at the nanoscale**
  - Highly sensitive probes ⟹ nano-sensors
  - Small volume ⟹ single qubit detection
  - Stronger interactions ⟹ hybrid systems

- **Systems**
  - Defects in diamond
  - Quantum dots
  - Rare earth doped crystals



Hard disk drive magnetic structure



100 nm

M. Pelliccione et al., Nat. Nanotechnol. (2016).

Rare Earth Doped Bulk Crystals

- **Very long lived quantum states @ 4 K**
  - Optical transition: up to 4.4 ms

    T. Böttger et al., Phys. Rev. B 79, 115104 (2009).
  - Spin transitions: up to 6 hours

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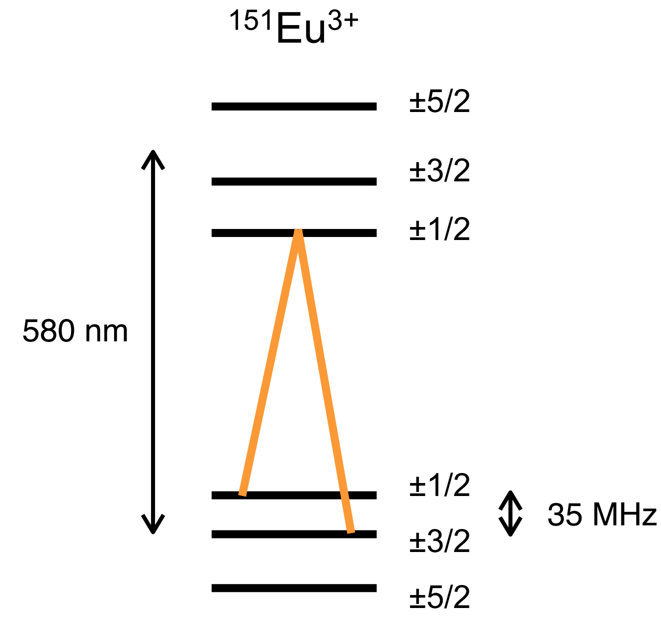
  - Λ-systems for optical to spin transfer



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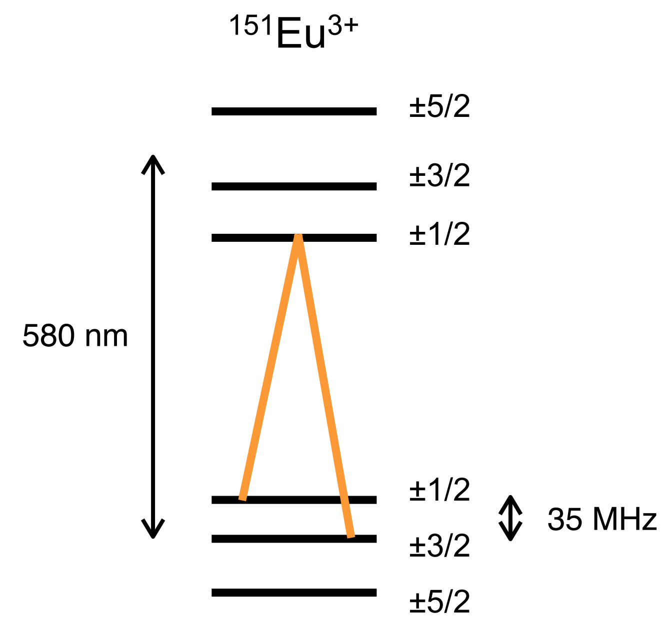
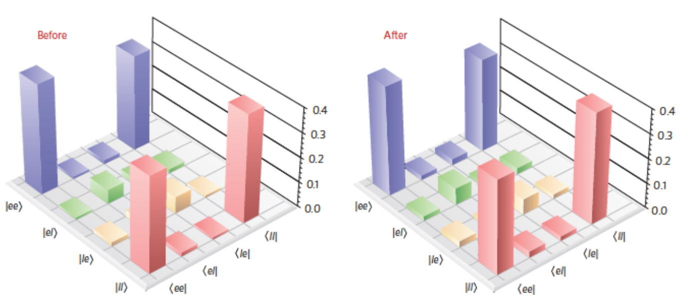


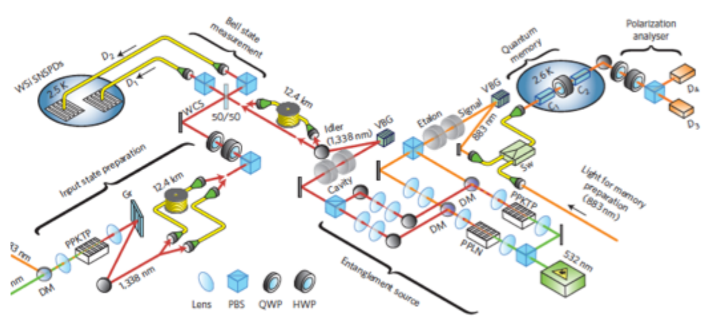
- **Quantum technologies**
  - Quantum storage

Storage at 1.5 µm



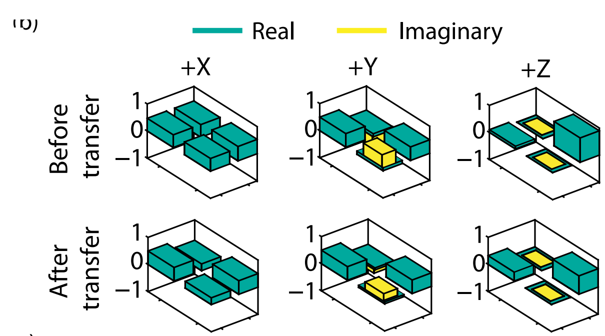
E. Saglamyurek et al., Nat. Photonics (2015)

Light matter teleportation



F. Bussières et al., Nat. Photonics (2014)

Microwave storage



G. Wolfowicz et al., Phys. Rev. Lett. (2015)

Rare Earth Doped Nanocrystals

- **Rare earth doped particles with size << λ:**
  - Single rare earth ion detection
  - Efficient coupling to high-Q optical resonators
  - Coupling to other quantum systems
  - New platform for light-matter quantum interfaces

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NV center electron spins in diamond:
bulk T_2 = 2.5 ms, nano: T_2 = 5 µs

Current Status

- **Optical homogeneous linewidth for $Eu^{3+}:Y_2O_3$ nanocrystals**
  - 60 nm crystallites (micron size particles)
  - **Γ_h = 86 kHz** (T_2 = 3.7 μs)

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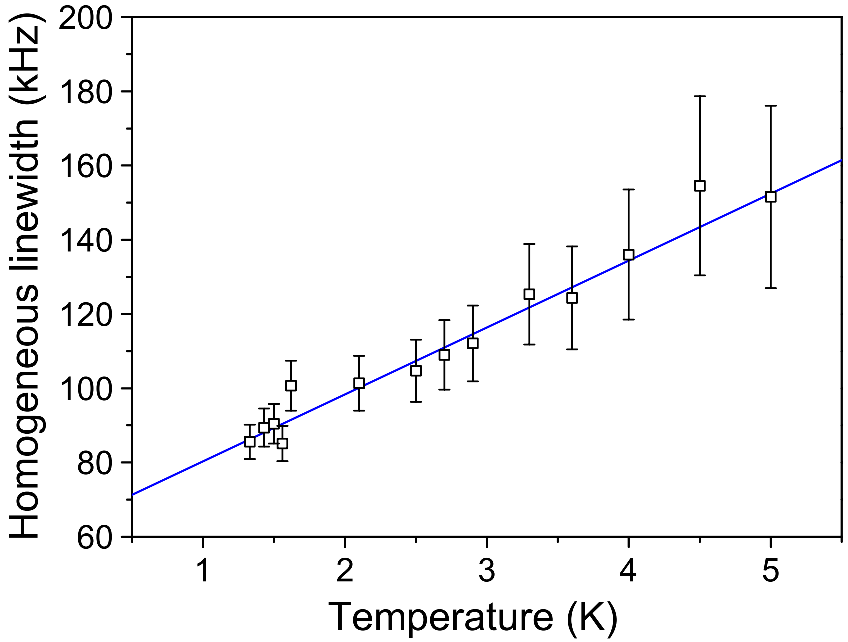

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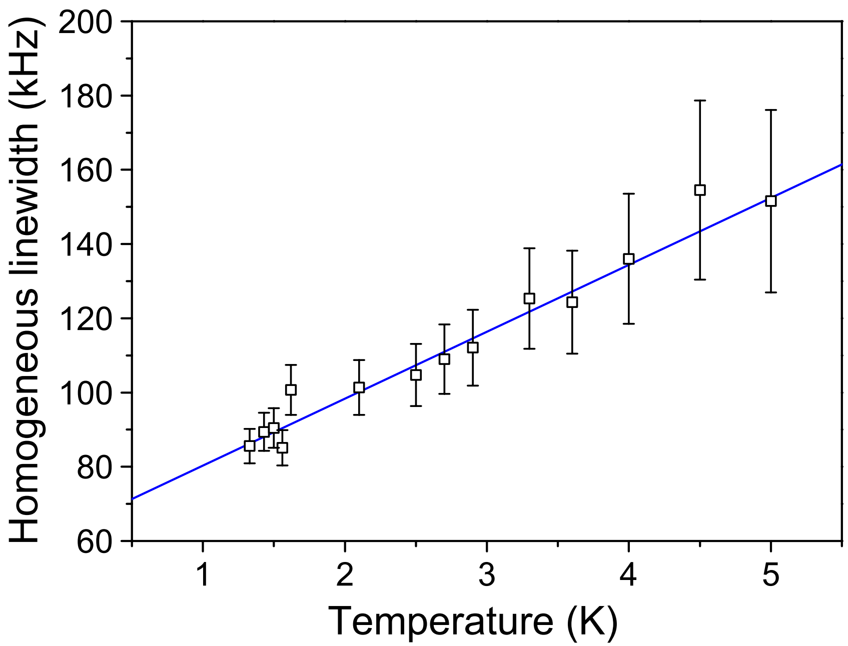

Can we improve? Bulk crystals: Γ_h down to 290 Hz!*
Is the additional dephasing intrinsic to the crystal size?

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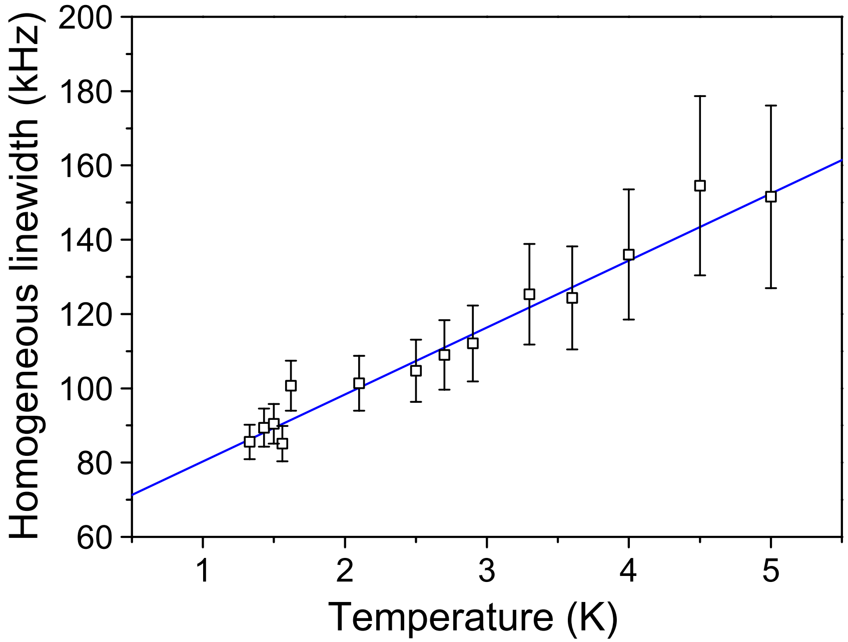

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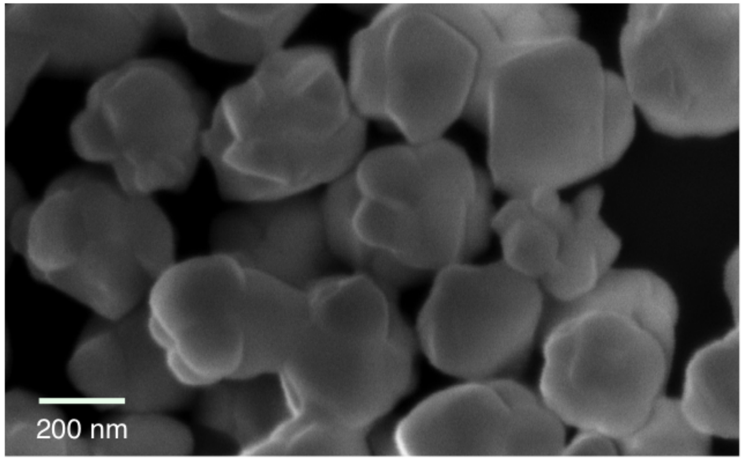
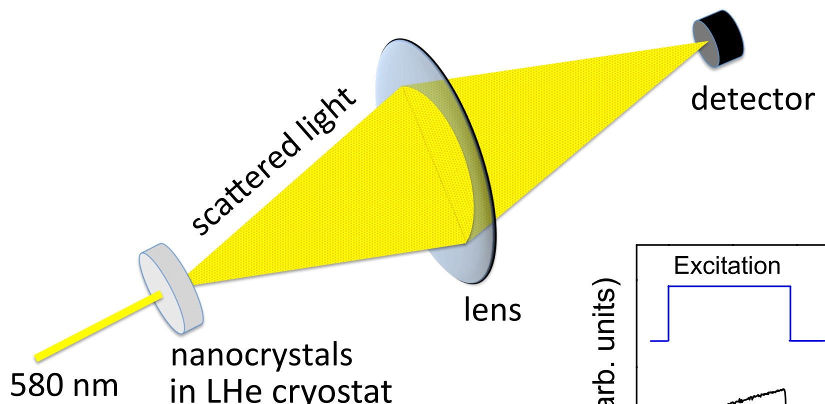
Optical homogeneous linewidths **unaffected in nano-resonators written in bulk crystals**

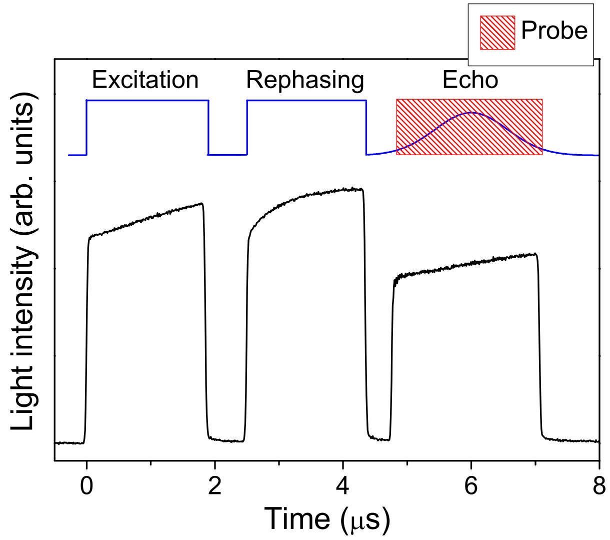
T. Zhong et al., Nat. Commun. 6, 8206 (2015).

$Eu^{3+}:Y_2O_3$ Nanoparticles



- **Sample**
  - particle size: 400 nm
  - crystallite size: 130 nm
  - controlled precipitation and high temperature annealing





- **Optical spectroscopy**
  - 0.5% Eu^{3+} concentration
  - samples in the form of powders
  - helium bath cryostat
  - spectral hole burning and photon echo experiments for Γ_h measurements

Broadening Processes

- **Identified perturbations at LHe temp.**
  - Magnetic: **electron/nuclear spins**
  - Two Level Systems (TLS): fluctuations linked to (weak) **disorder**
  - Phonons: 1- and 2-phonon processes,
    modified phonon density of states for nanoparticles

Y. C. Sun, in Spectroscopic Properties of Rare Earths in Optical Materials, (Springer, 2005).
P. Goldner et al., Handbook on the Physics and Chemistry of Rare Earths, Vol. 46 (Elsevier, 2015).
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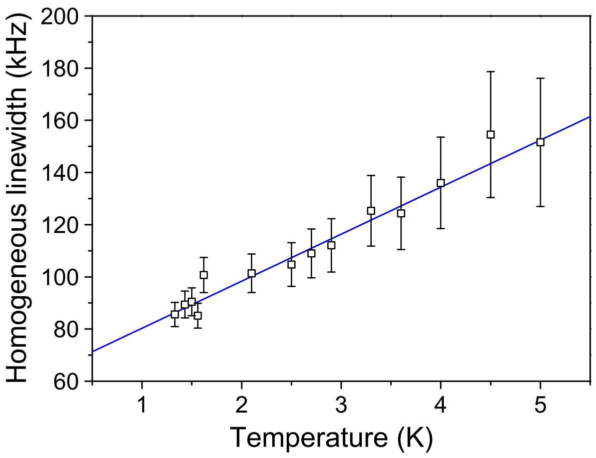
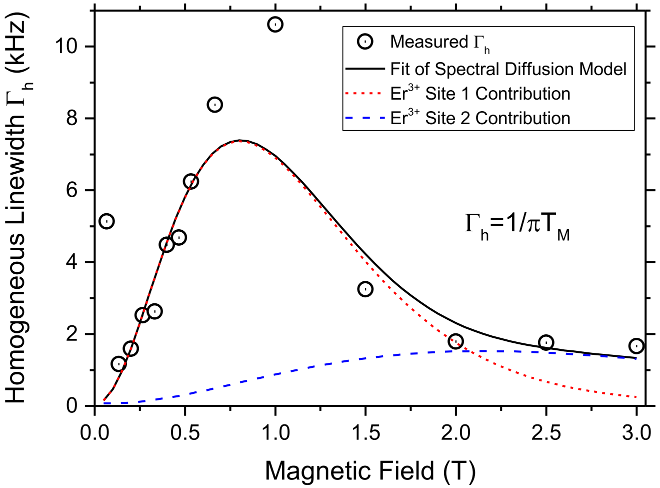
- **Probed by:**

Phonons, TLS: temperature dependence



A. Perrot et al., Phys. Rev. Lett. 111, 203601 (2013).

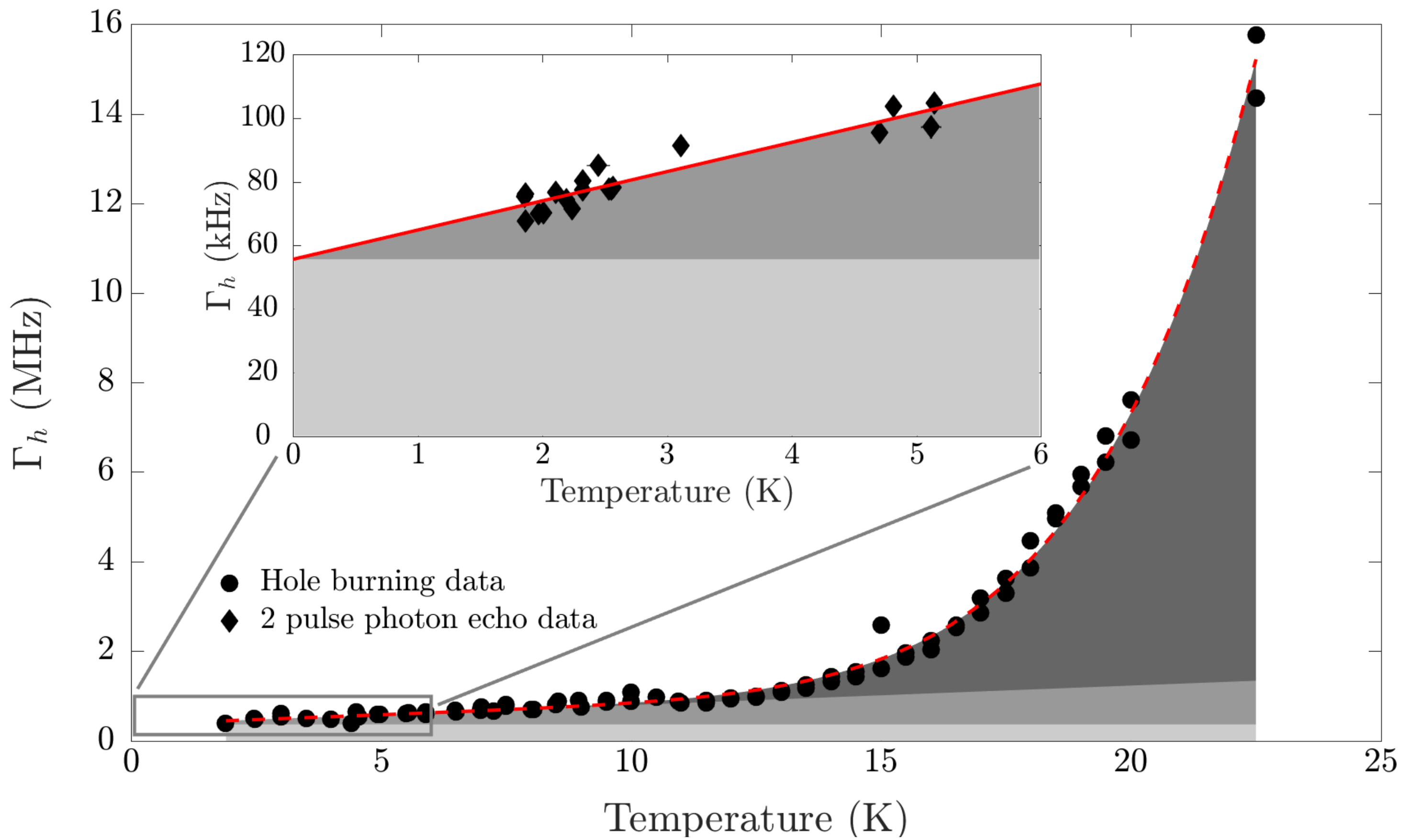
Spins: external magnetic field



S. Welinski et al., Opt. Mat. (2016).

Optical Homogeneous Linewidth - Temperature

Eu:Y_2O_3 particles



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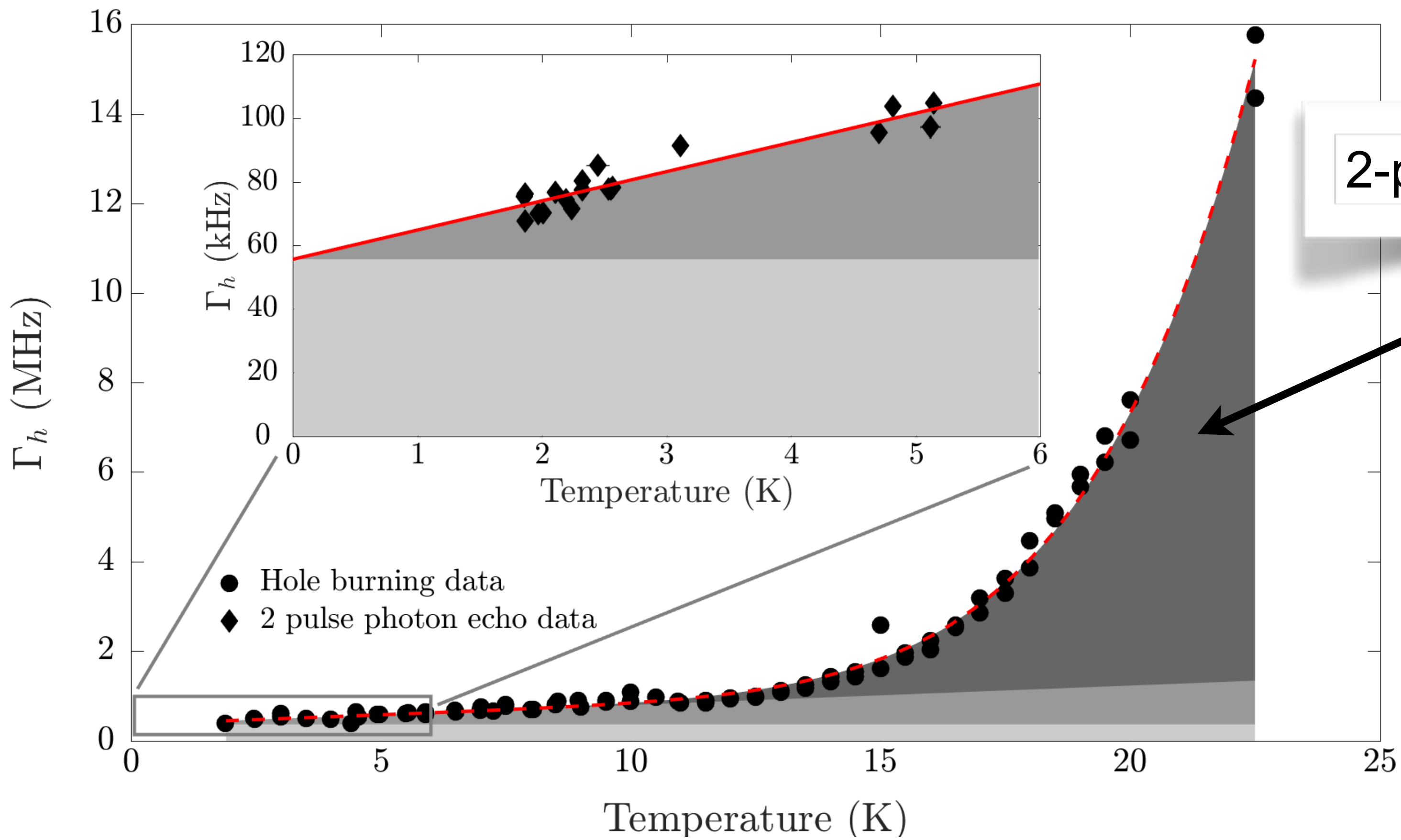

2-phonon Raman process

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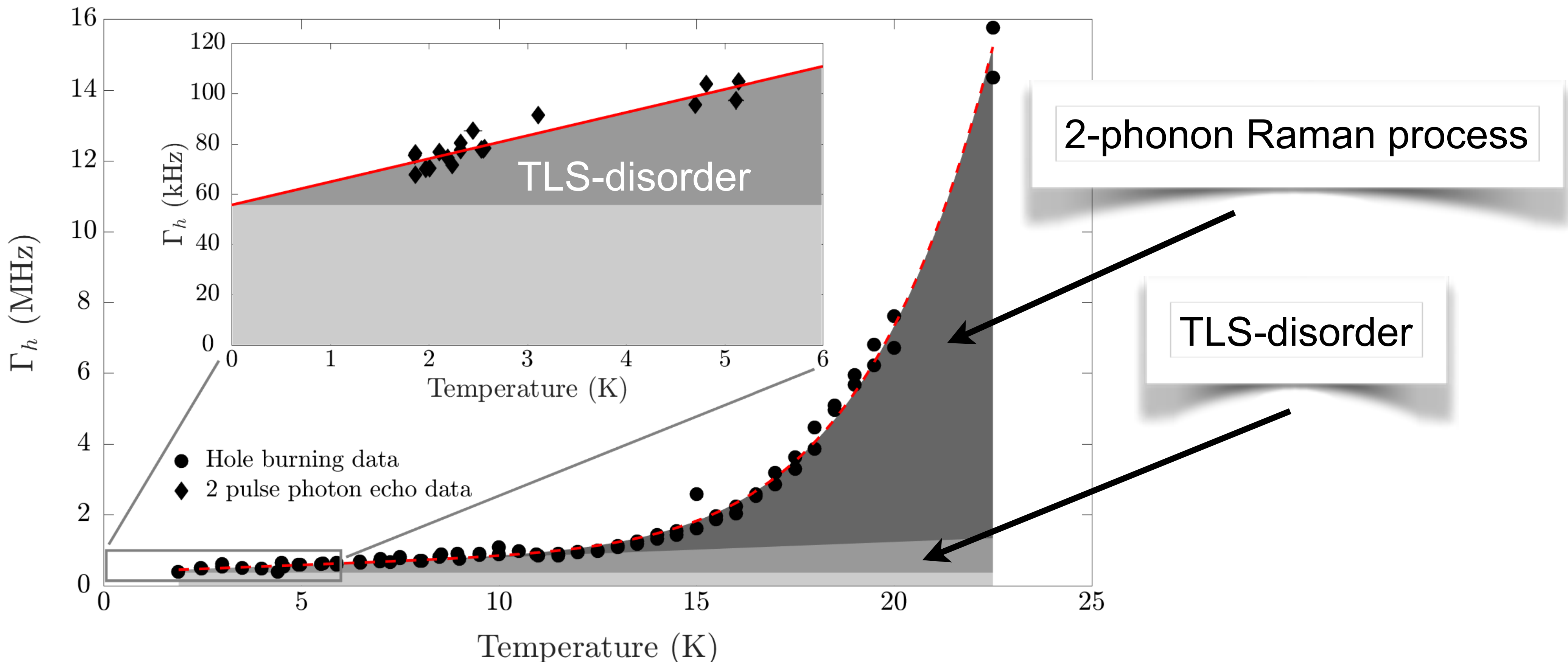

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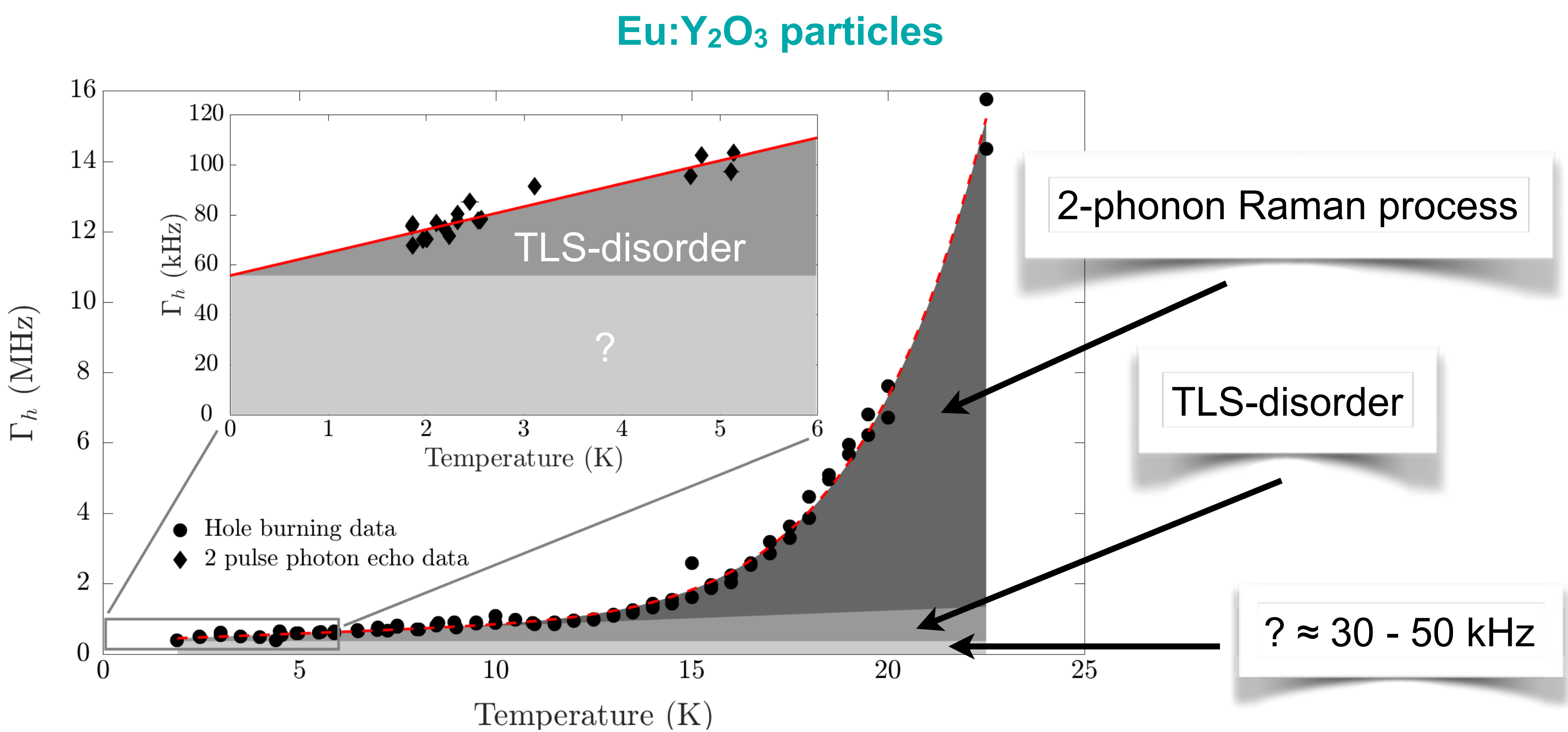

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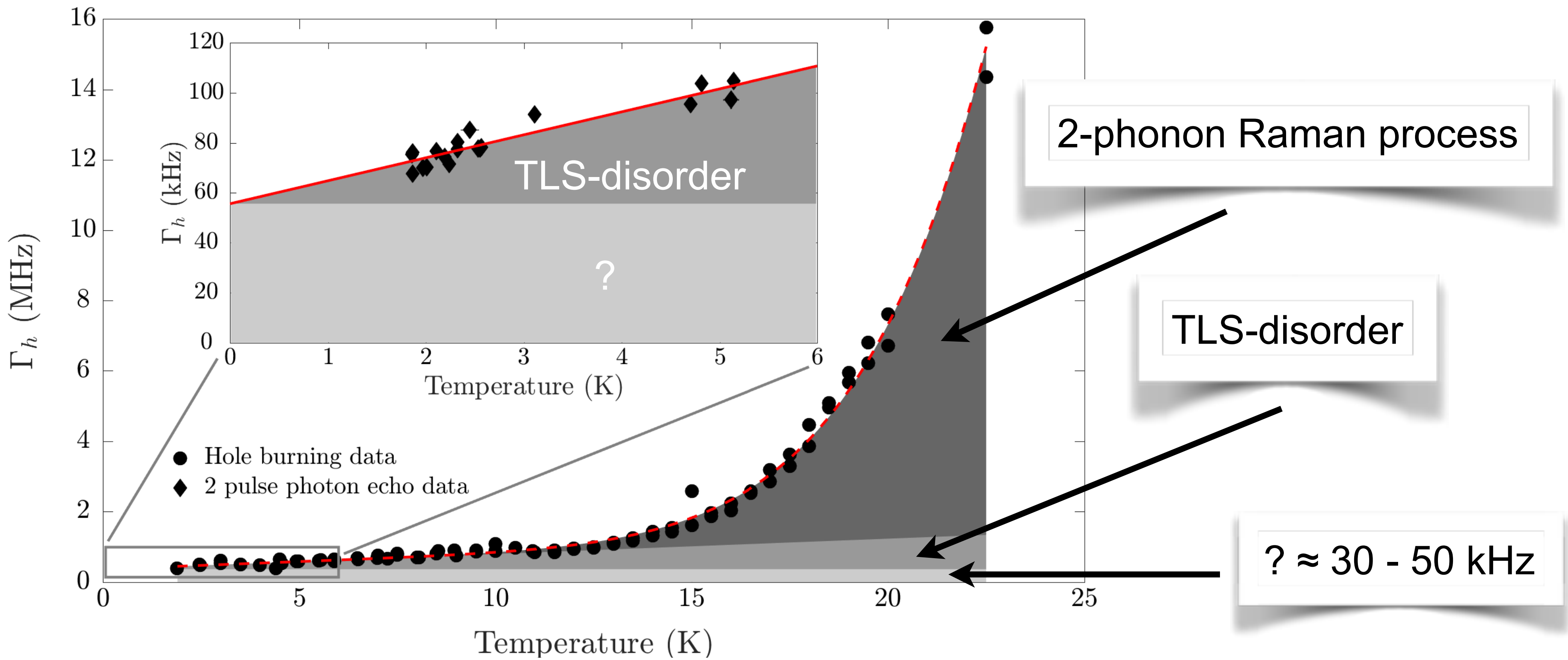
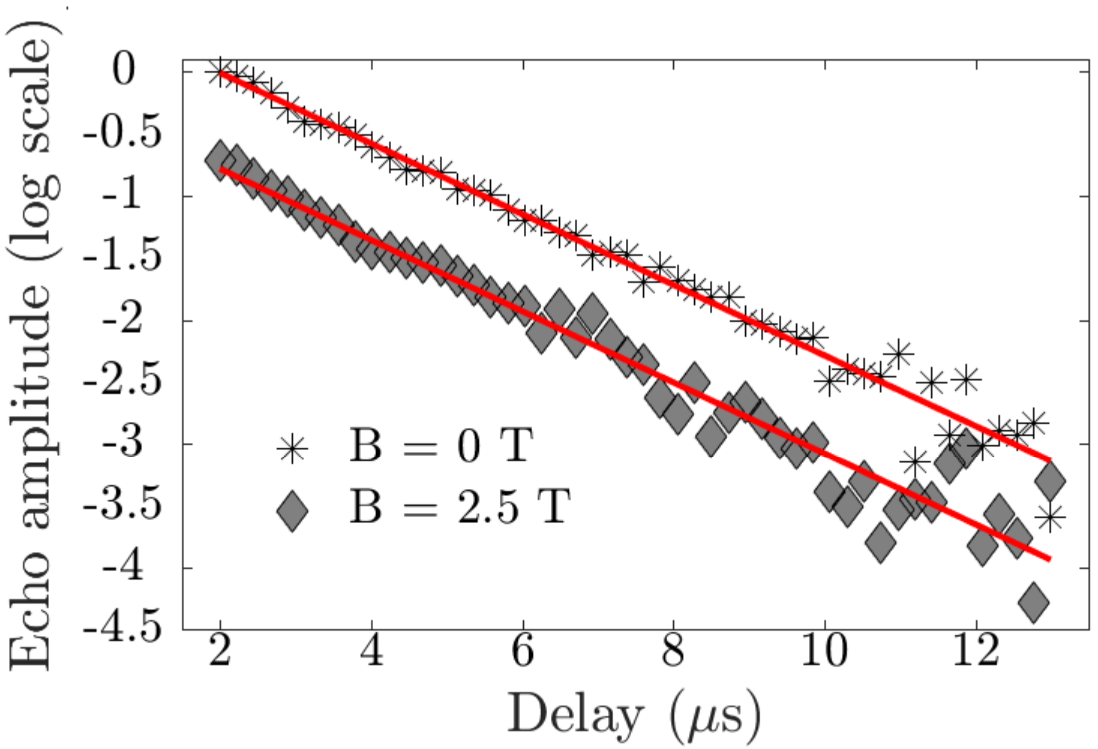


No sign of modified phonon density of states
45 kHz linewidth observed (T_2 = 7 µs)

Magnetic Field Effect



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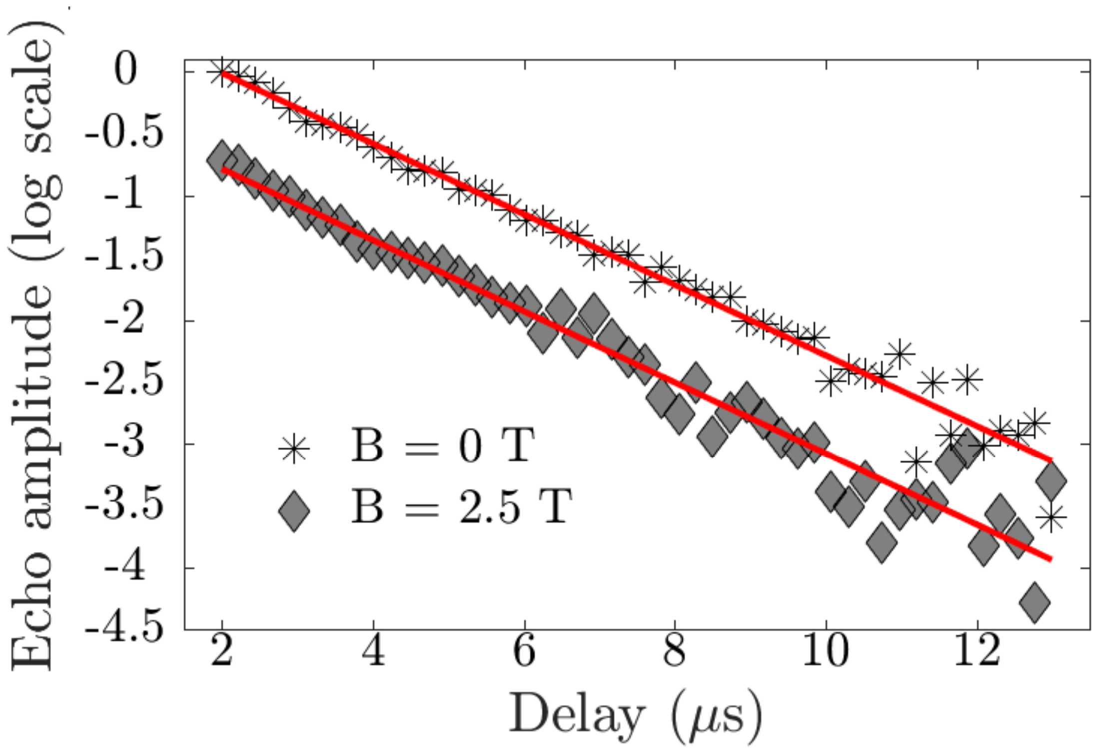

No effect of the external magnetic field
Spins are unlikely to produce the unknown contribution

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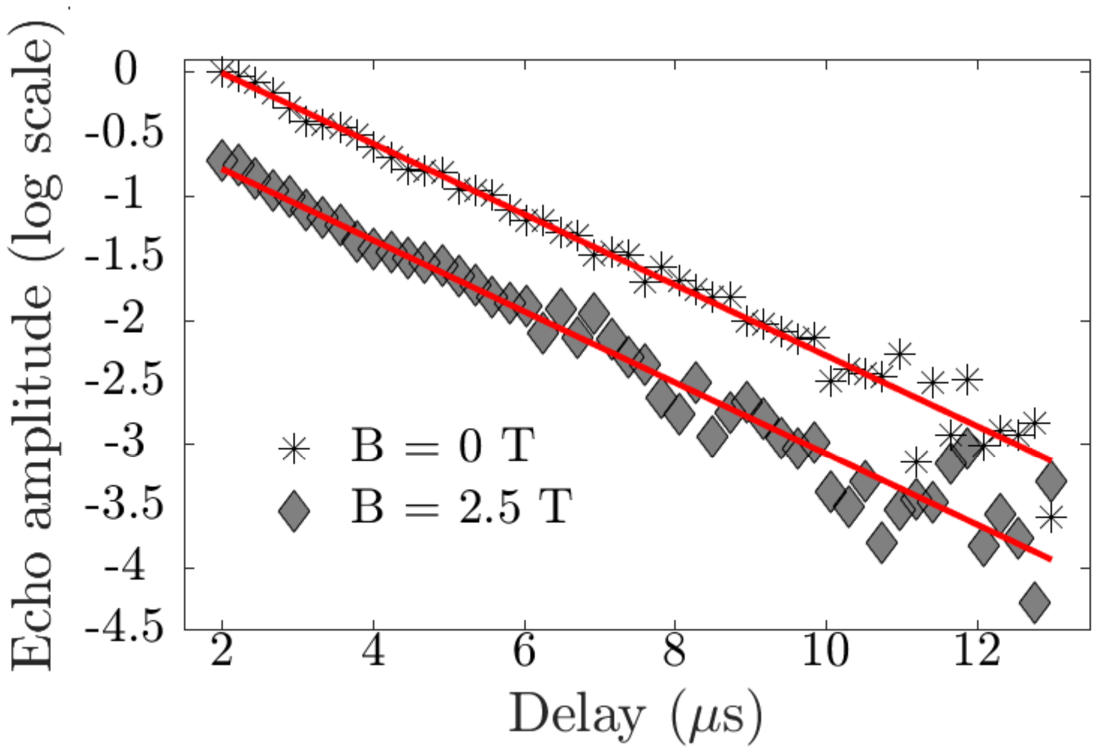

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Electrical noise from surface charges?

Stark Effect

- **Optical transitions:**
  - different permanent electric dipole moments in the ground and excited states
  - 50 kHz/(V/cm) in $Eu^{3+}:Y_2O_3$ (average value)

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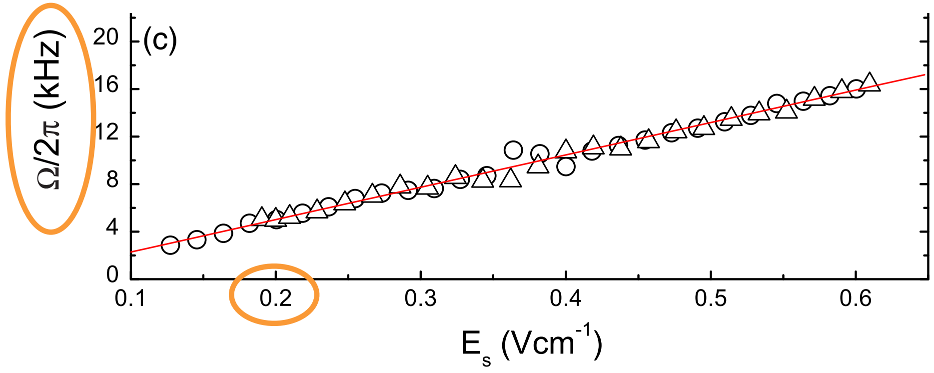

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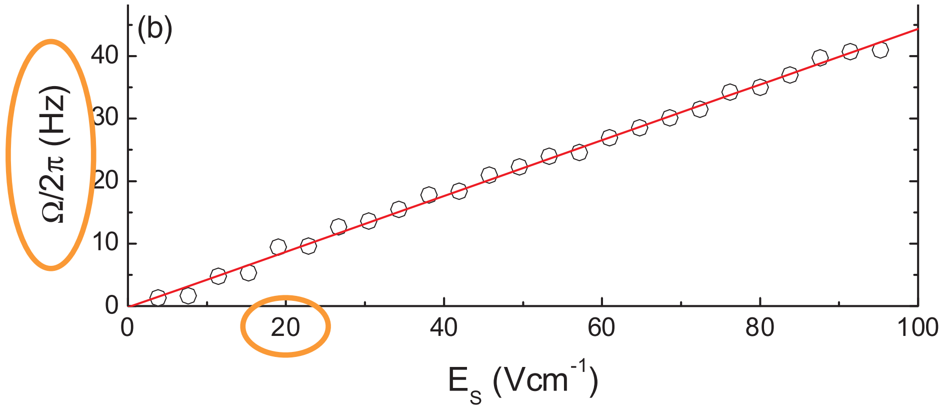

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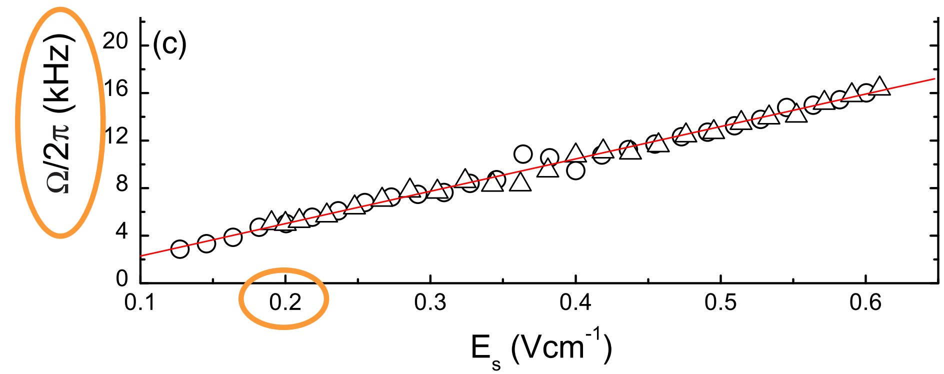

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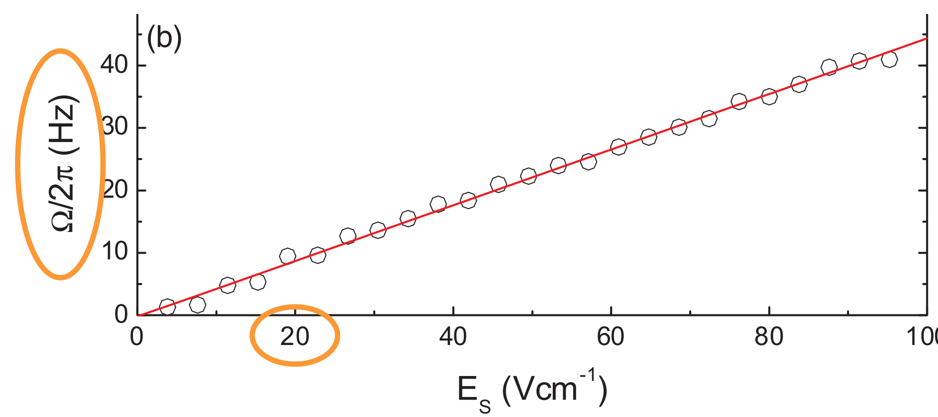
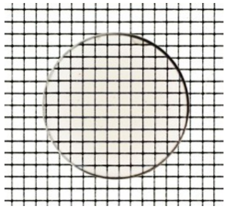


Spin transitions unaffected by electrical noise

Spin Homogeneous Linewidth

- Eu^{3+}:Y_2O_3 transparent ceramics, μ size crystals
- **optical Γ_h = 4.7 kHz** (bulk crystal: 290 Hz)



Synthesized by Dr. Akio Ikesue, World Lab Co., Japan

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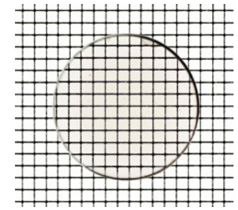

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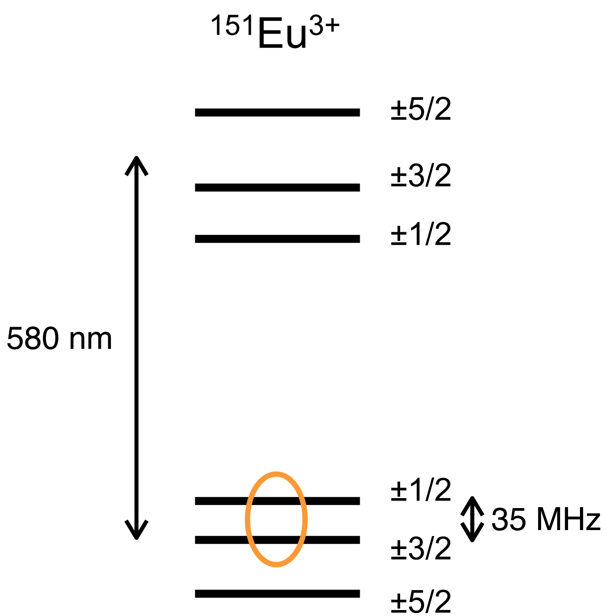

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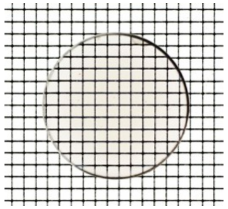

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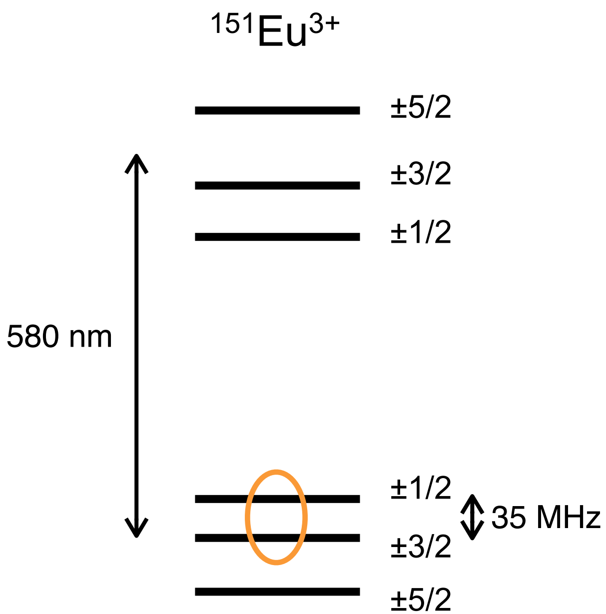

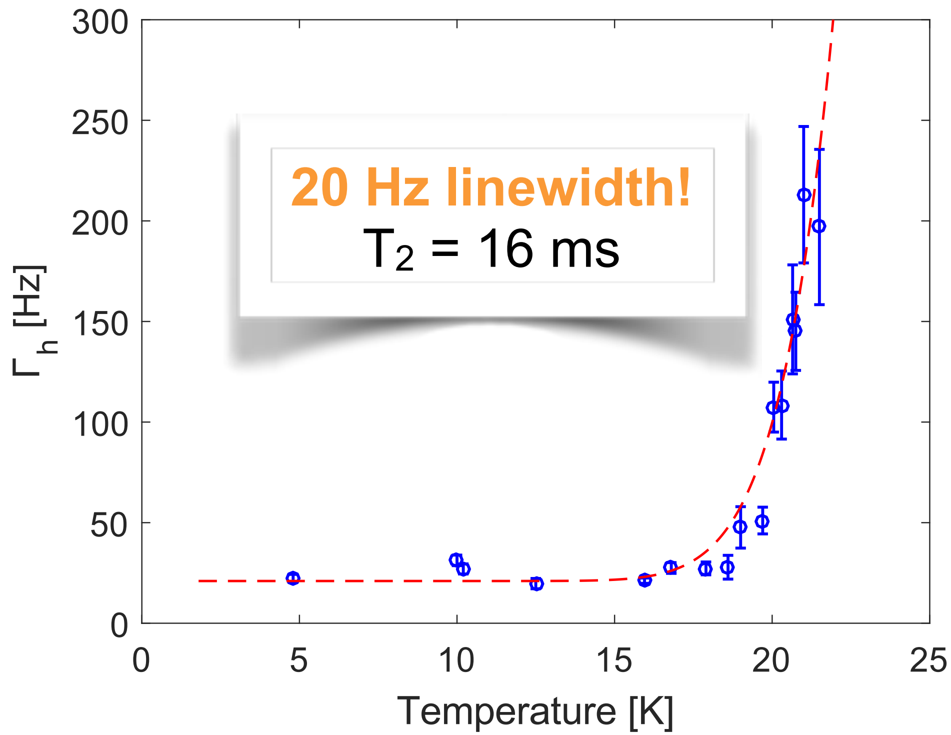

J. Karlsson et al., J. Phys.: Condens. Matt, in press

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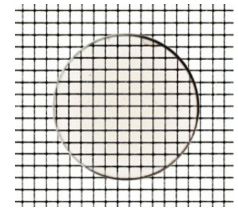

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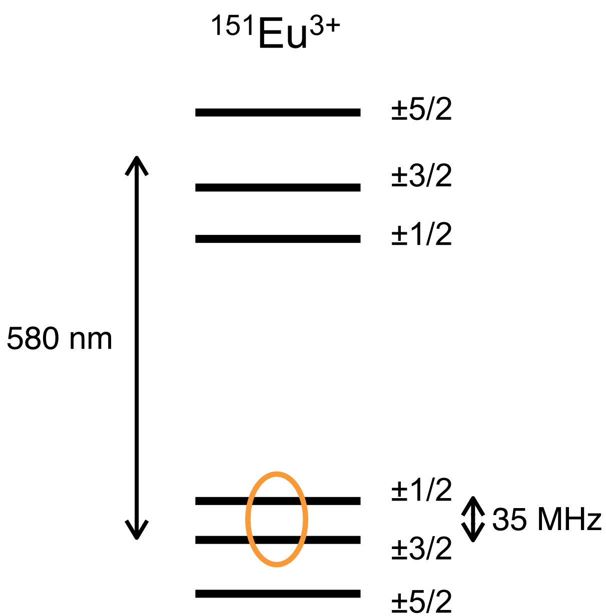

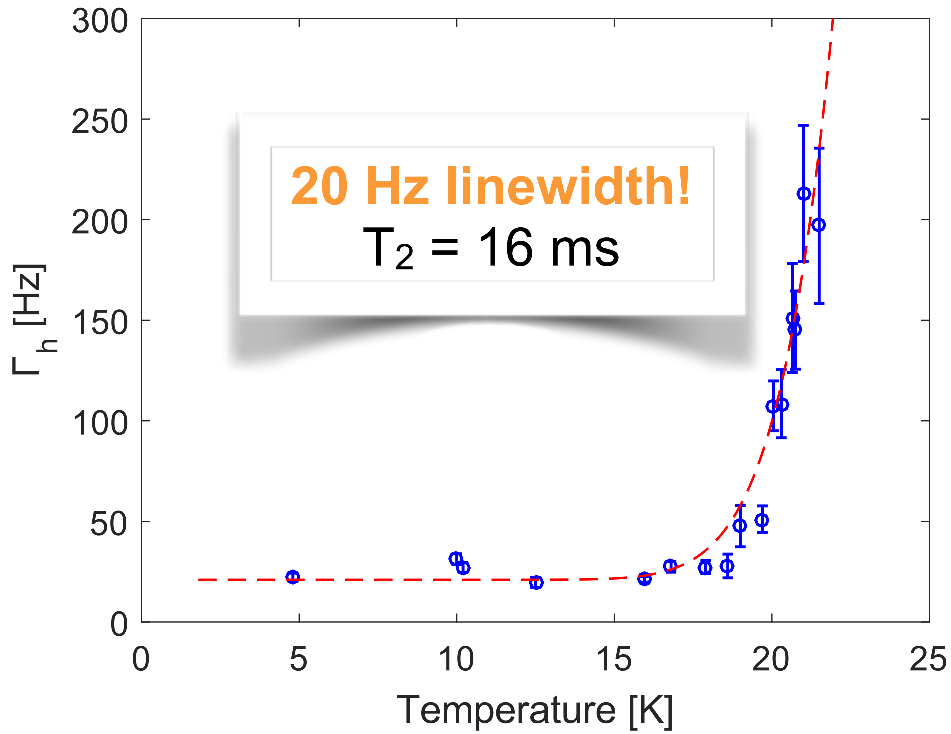

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Very narrow spin linewidths despite broad optical transition

Conclusion

- **45 kHz optical homogeneous linewidths** observed in rare earth doped nanocrystals
- Linewidths likely to be dominated by **electrical noise**
- Spin transitions (qubit) should be **much less affected**
- **20 Hz spin linewidth** (T_2 = 16 ms) observed in micron size crystals

Long lived nanoscale light-atom-spin interfaces may be possible!

Funding:

European Union's Horizon 2020 project NanOQTech

NanOQTech

Nanoscale Systems for Optical Quantum Technologies

http://www.nanoqtech.eu

ANR/NSF project Discrys

PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR

Group web page: http://www.cqsd.fr