

# Spin Noise Spectroscopy

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# Outline

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- Motivation
- What is Spin Noise?
- Experimental setup
- Measurements
  - Semiconductors (3D, 2D, 0D GaAs, silicon)
  - Rubidium gas
- Conclusion

# Motivation

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## How to measure ...

- spin dynamics
- electron Landé g-factor

## without

- excitation of electron hole pairs  
(pump-probe Faraday rotation, time resolved photoluminescence)
- heating of the sample?  
(possible in ESR)

-> **Spin Noise Spectroscopy!**



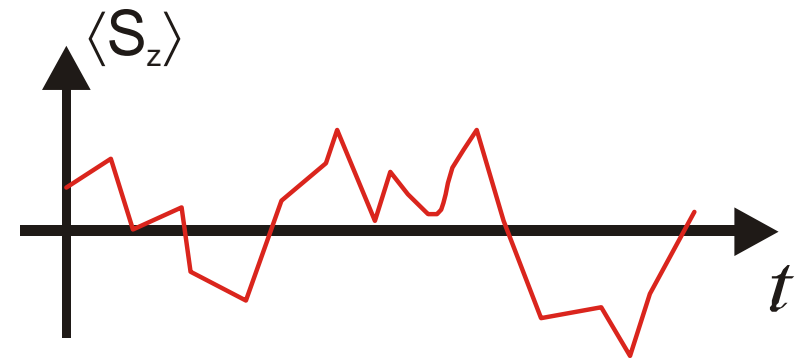
# What is spin noise?

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Assume  $N$  independent donor electrons in a low  $n$ -doped GaAs sample  
or  
 $N$  independent atoms (e.g. Rubidium gas)



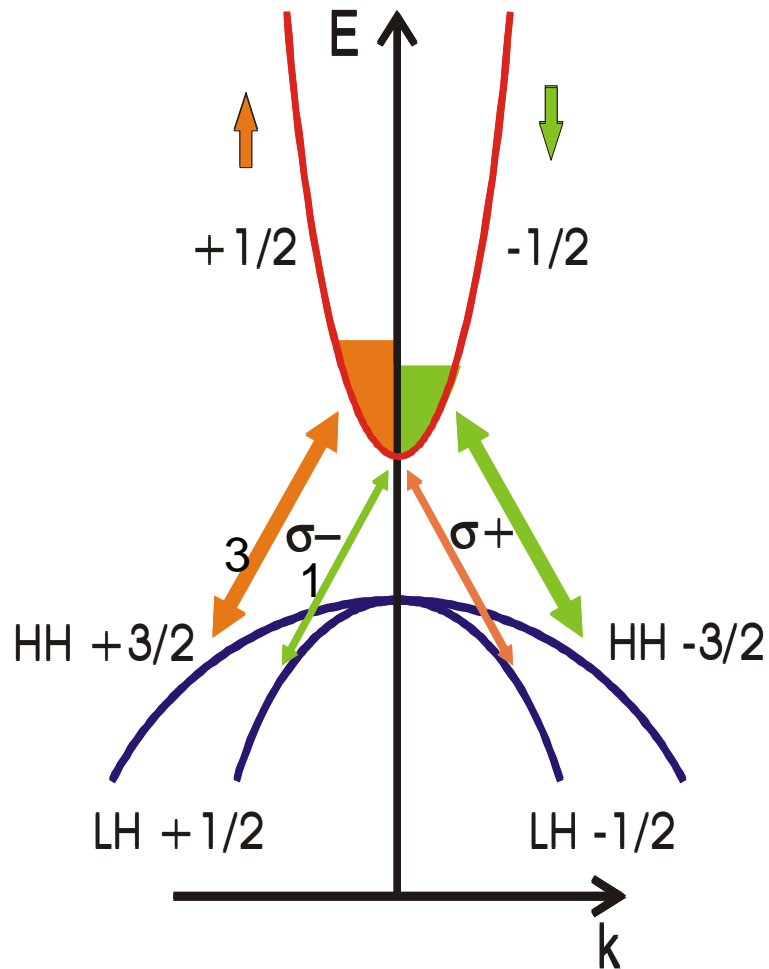
Fluctuating electron spin polarization  $\langle S_z \rangle$ :



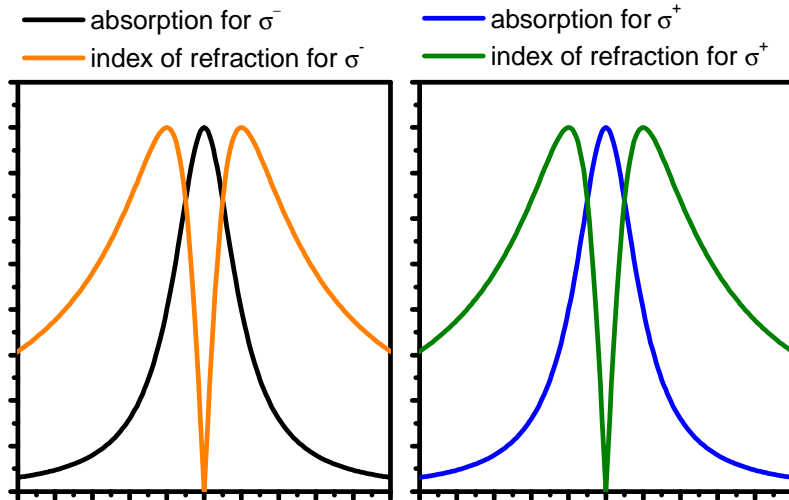
in average  $\sqrt{N}$  electron spins are spin oriented (Poisson distribution)

# Optical selection rules

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CB

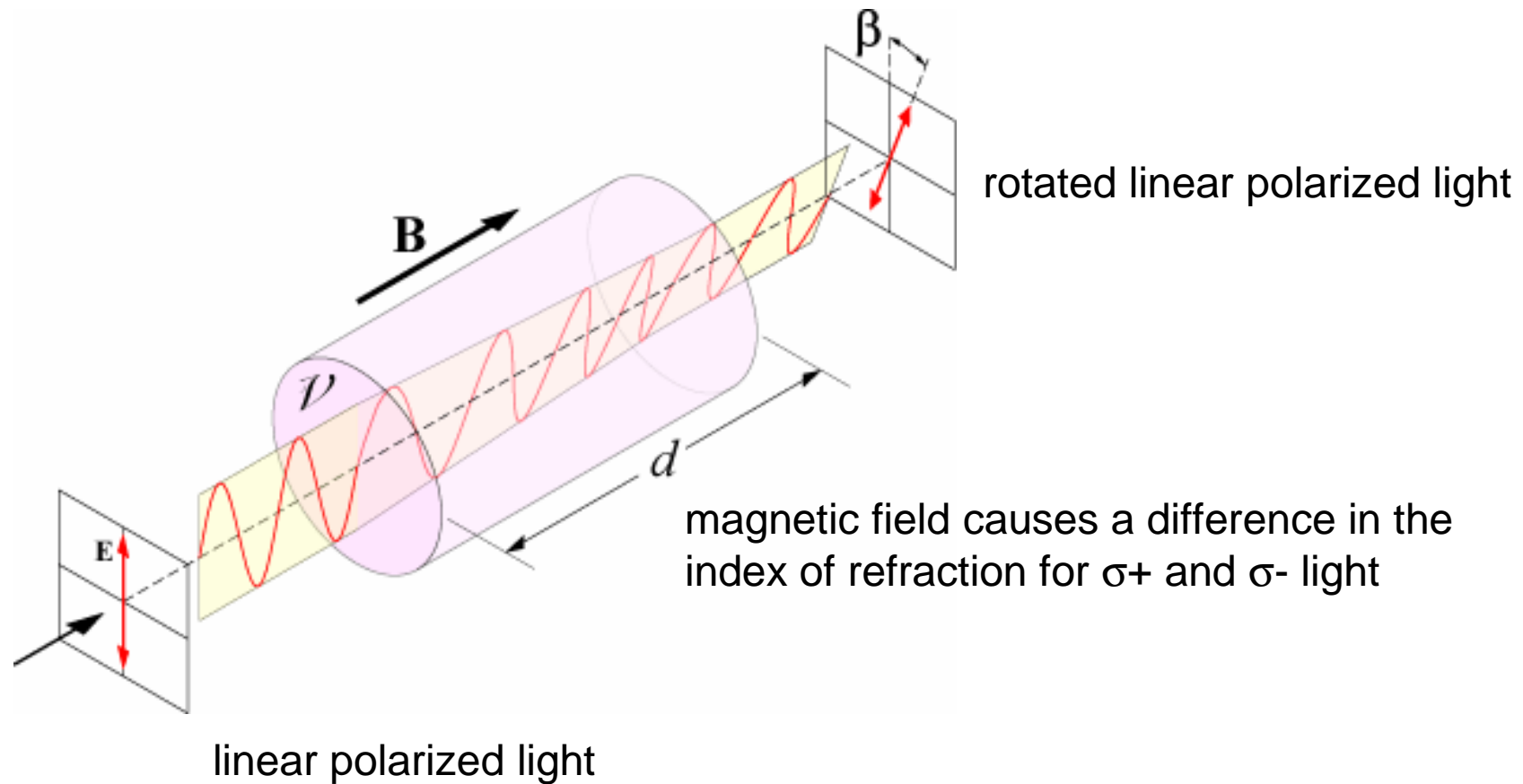


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- Random spin polarization causes unequal population of spin up and spin down sub bands
- Suppression of the optical transitions due to phase-space filling maps the spin fluctuations onto the absorption coefficient

# Faraday rotation

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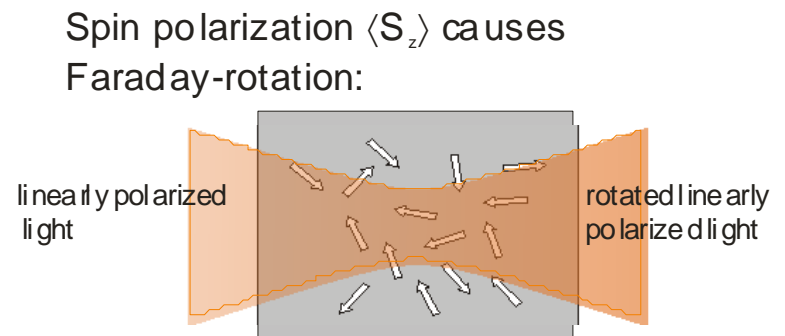
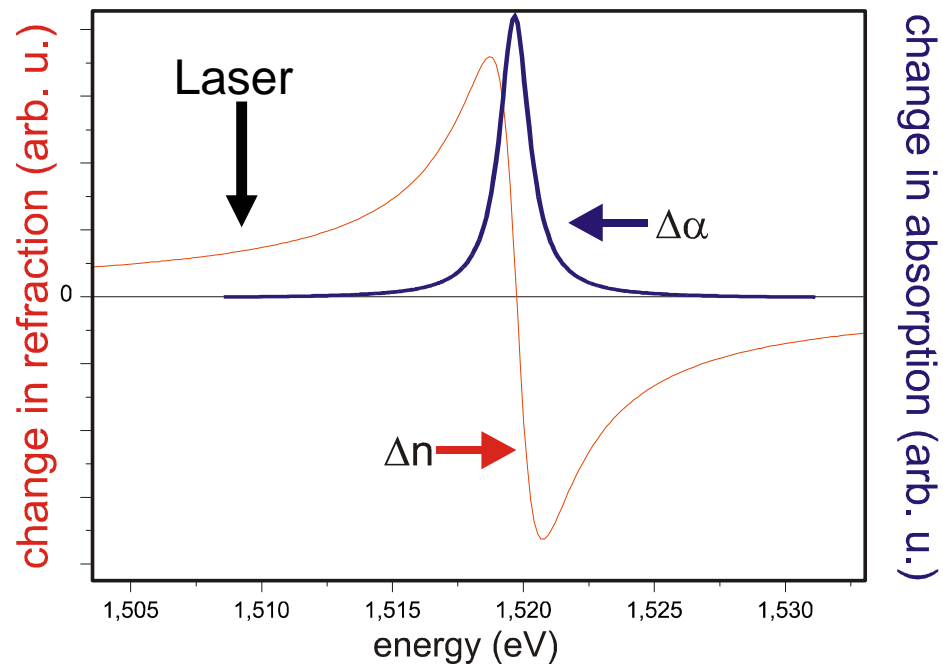


# Detection via Faraday rotation

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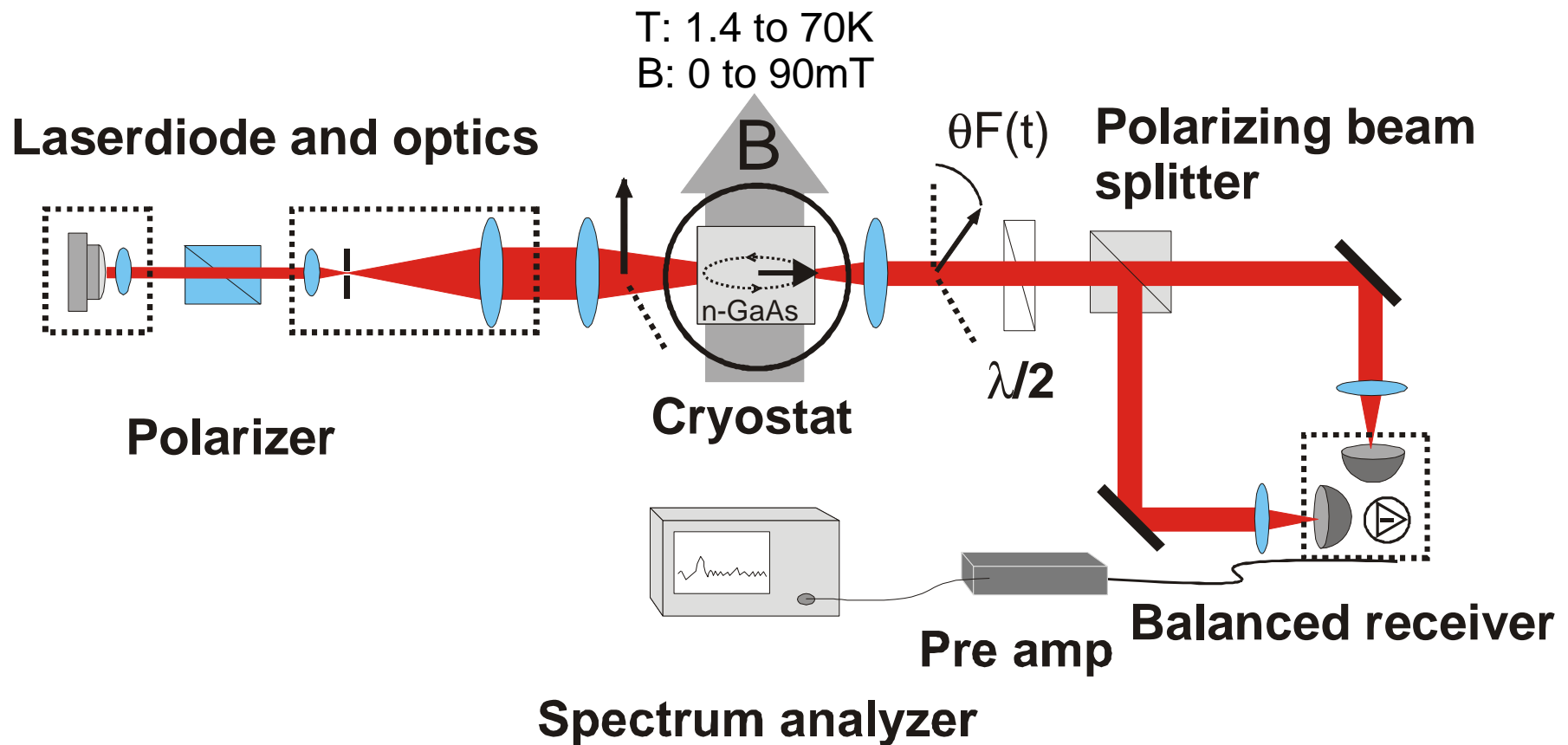
Spin polarization acts as an effective magnetic field

Calculated change in  $\alpha$  and  $n$ :



# Experimental setup

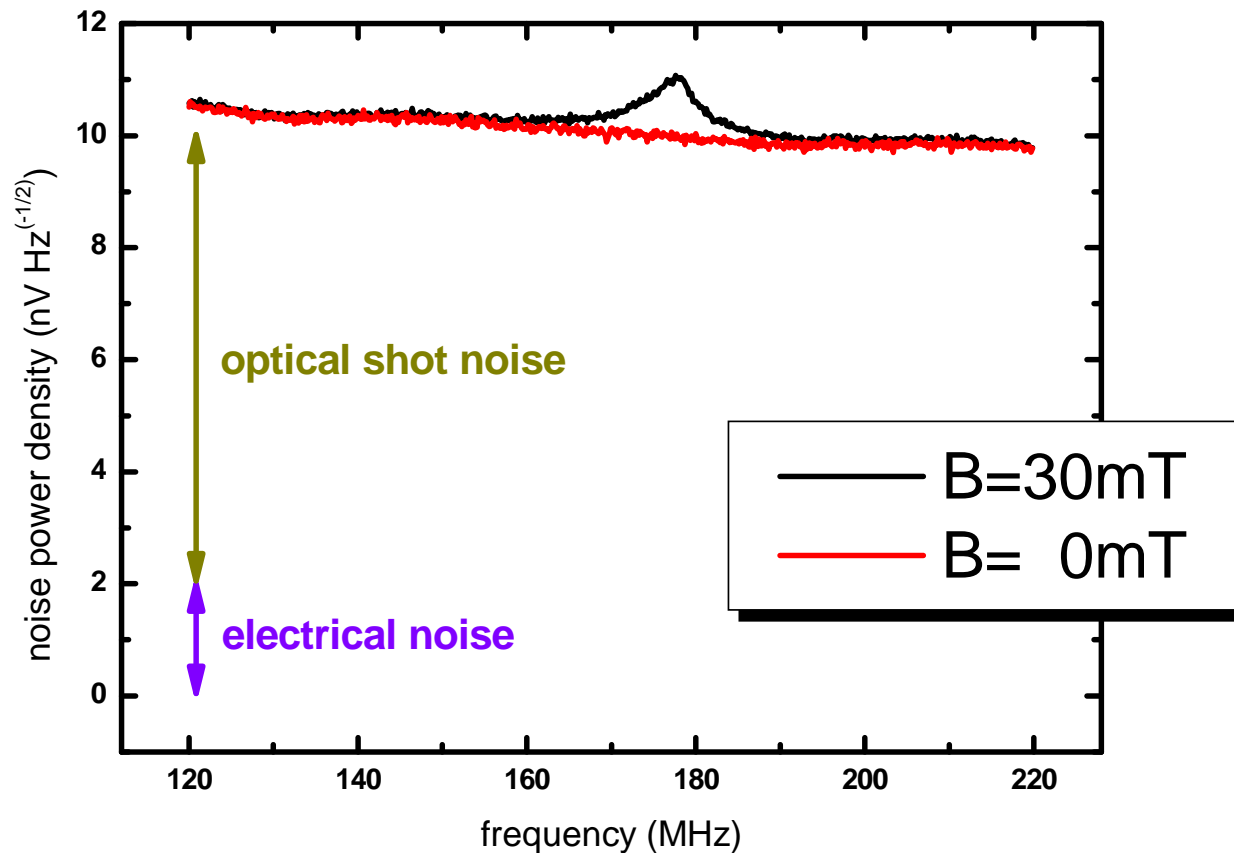
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# Noise levels – difference spectra

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A trace containing no spin noise signal is subtracted to eliminate white background noise



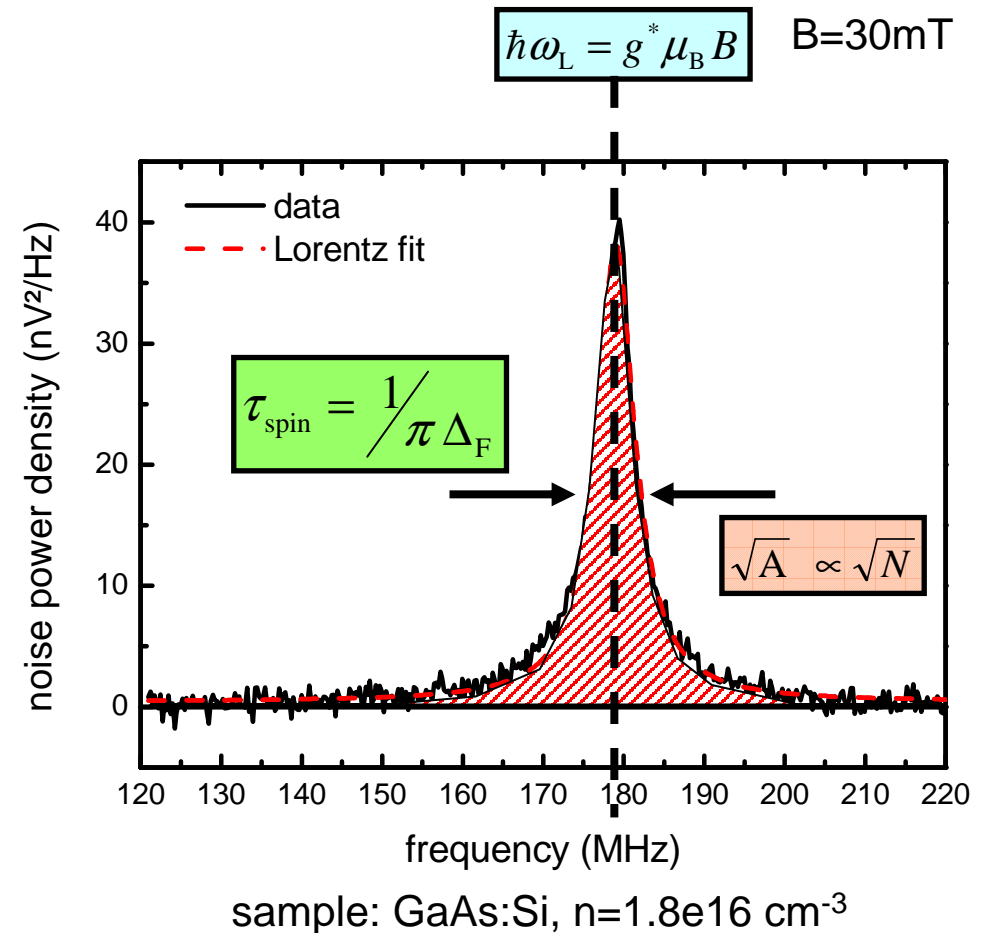
# Noise spectrum

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The spectrum contains information about

- electron Landé  $g$ -factor
- spin relaxation time
- spin correlations

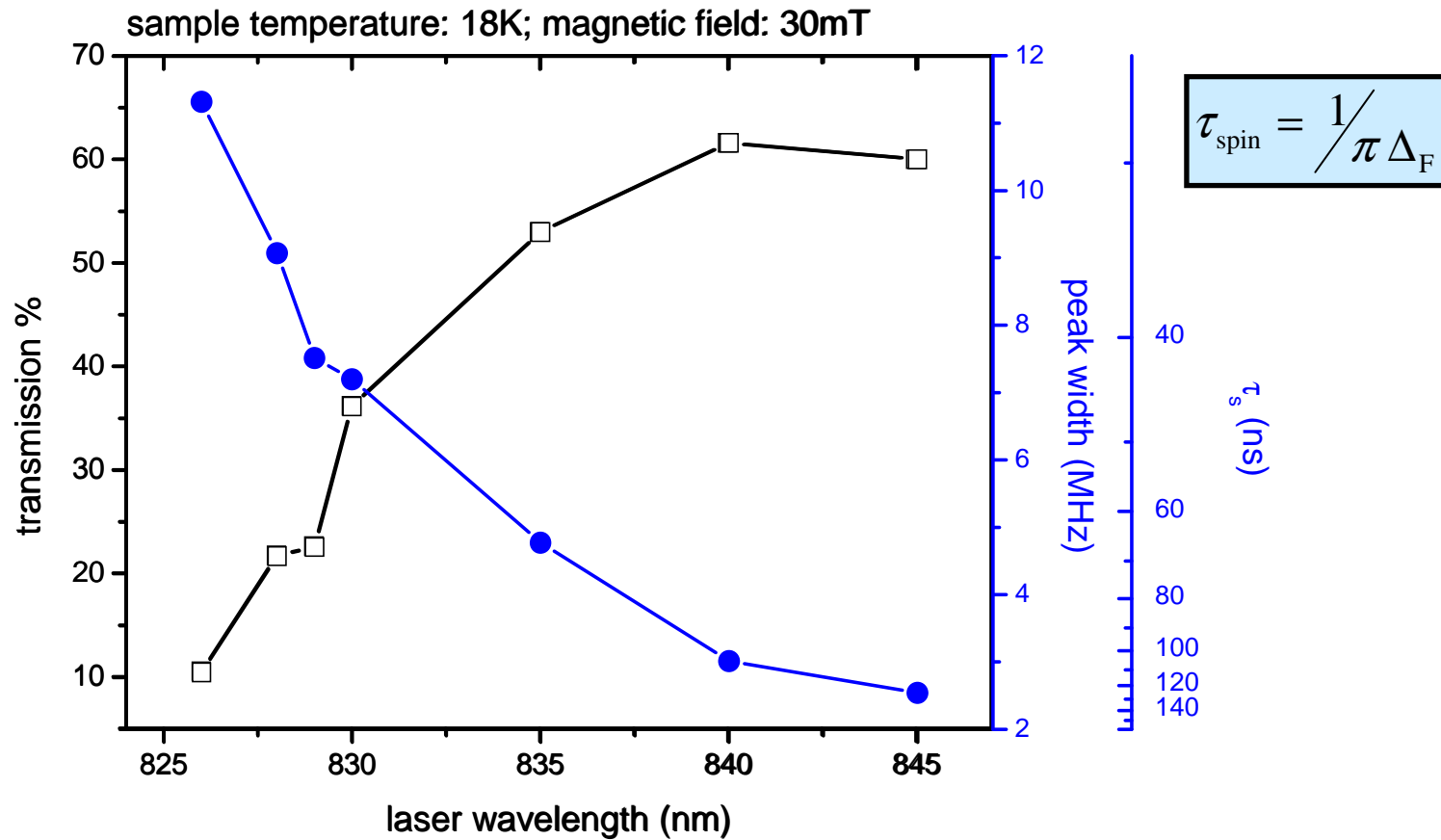
dependent on doping concentration



# Wavelength dependence of $\tau_s$

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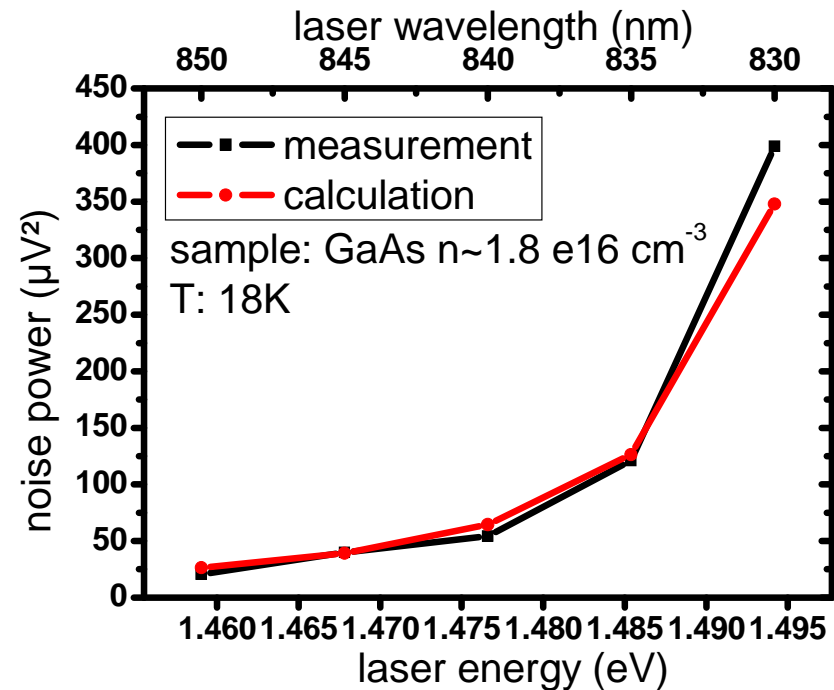
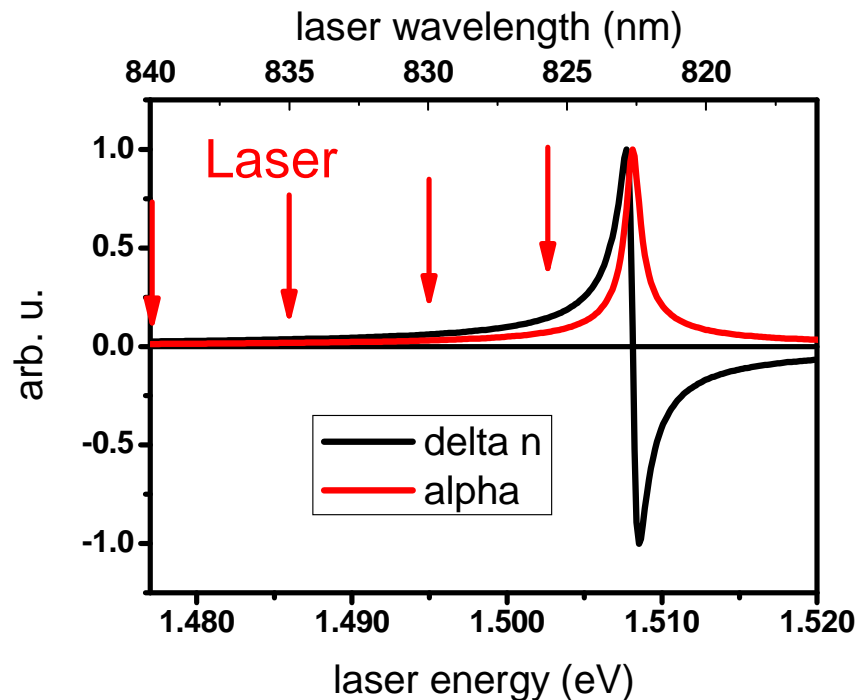
Wavelengths further away from the resonance reduce remaining perturbations ...



# Wavelength dependence 2

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... at the cost of reduced signal strength.



GaAs:Si,  $n=1.8\text{e}16 \text{ cm}^{-3}$  @ 18K

# Application

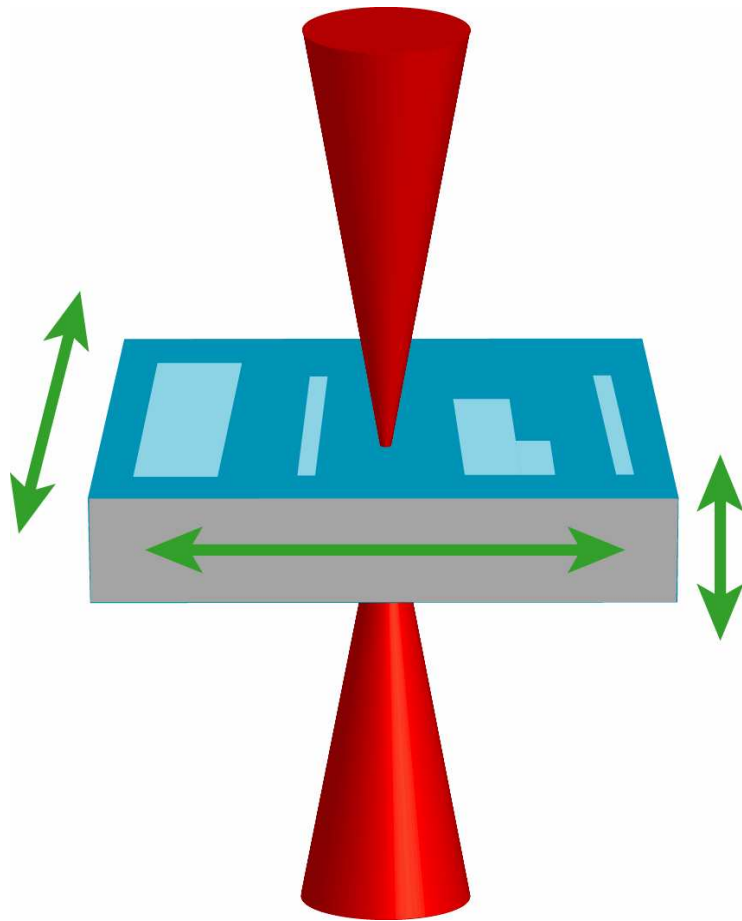
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- Non contact method to measure donor concentration in direct gap semiconductors with high spatial resolution.



# Spatially resolved measurement

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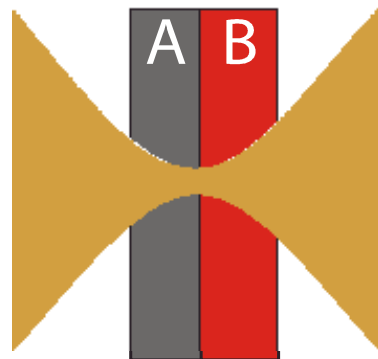


- SNS can be used to obtain spatially resolved data
- Noise power scales with  $1/A$
- Most of the signal is generated inside the Rayleigh range of the laser beam

# Depth resolved measurement

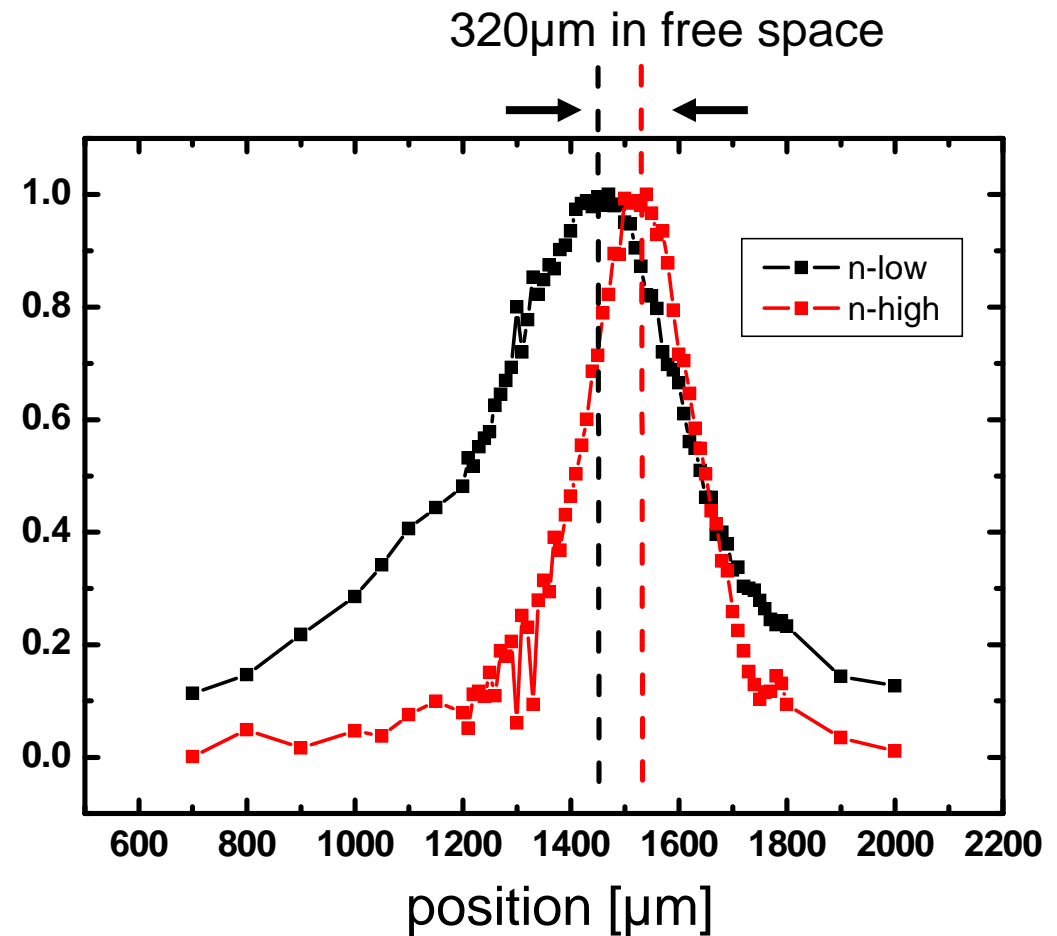
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laser beam



sample stack

normalized noise power



# Fundamental research

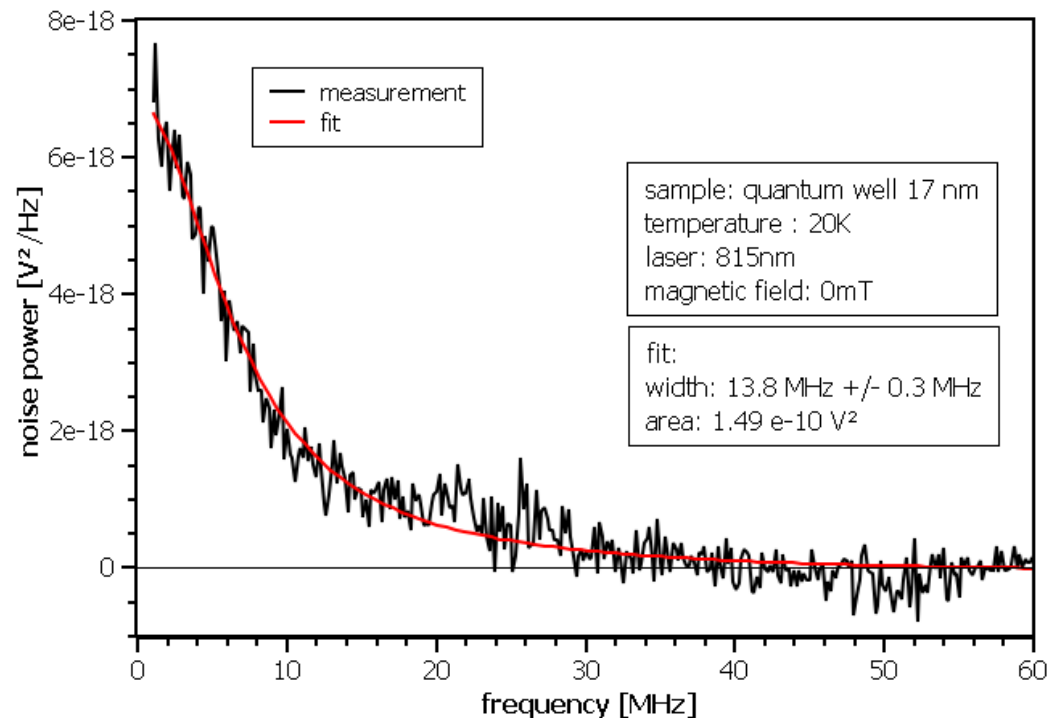
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- 110 GaAs QWs
- Donors in GaAs as artificial atoms
- Intrinsic spin relaxation time in silicon
- Rubidium gas

# Quantum wells

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- First SNS measurements in 110 QW



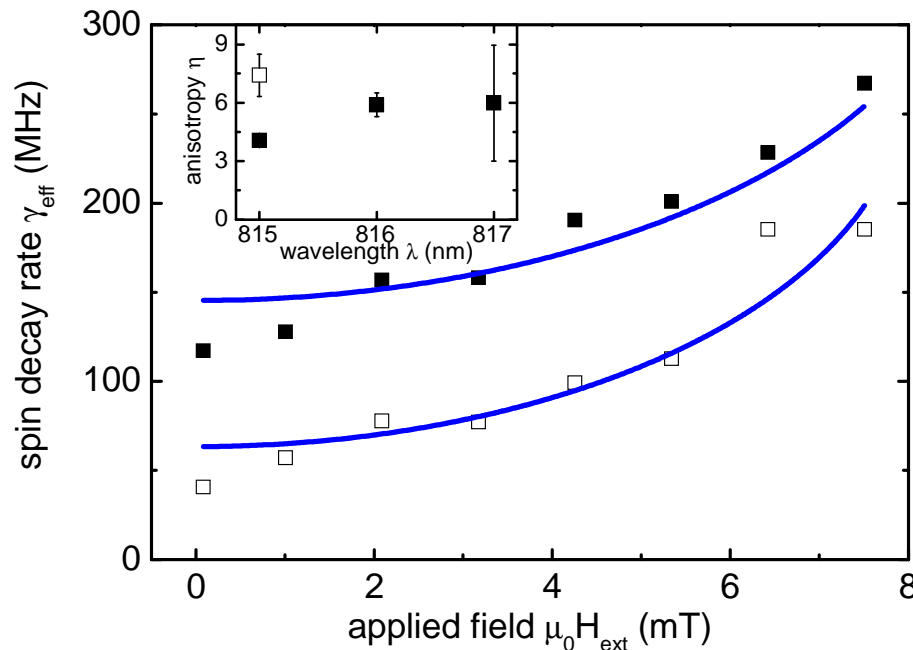
$\tau_s = 23$  ns

Poster by Georg Müller

# Anisotropic spin relaxation

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- By avoiding BAP and carrier heating SNS allows access to the intrinsic spin behavior



SNS can measure the anisotropic spin relaxation in 110 QWs even at low temperatures.

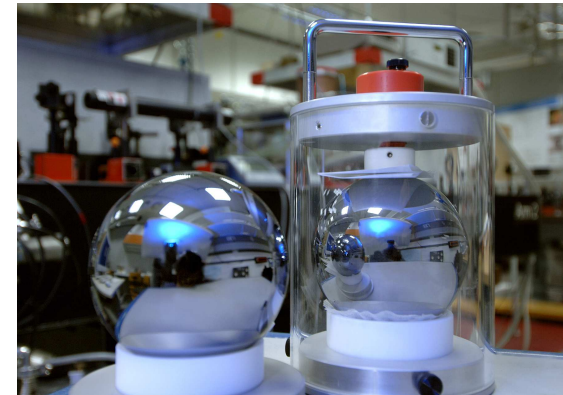
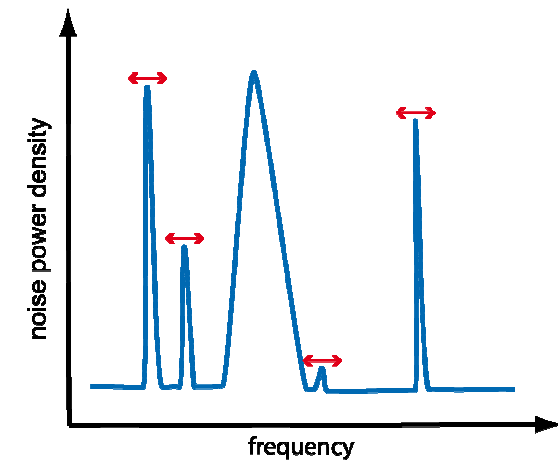
Measurement conditions:  
laser wavelength: 815 nm  
sample temperature: 20 K

Poster by Georg Müller

# Outlook: Semiconductors

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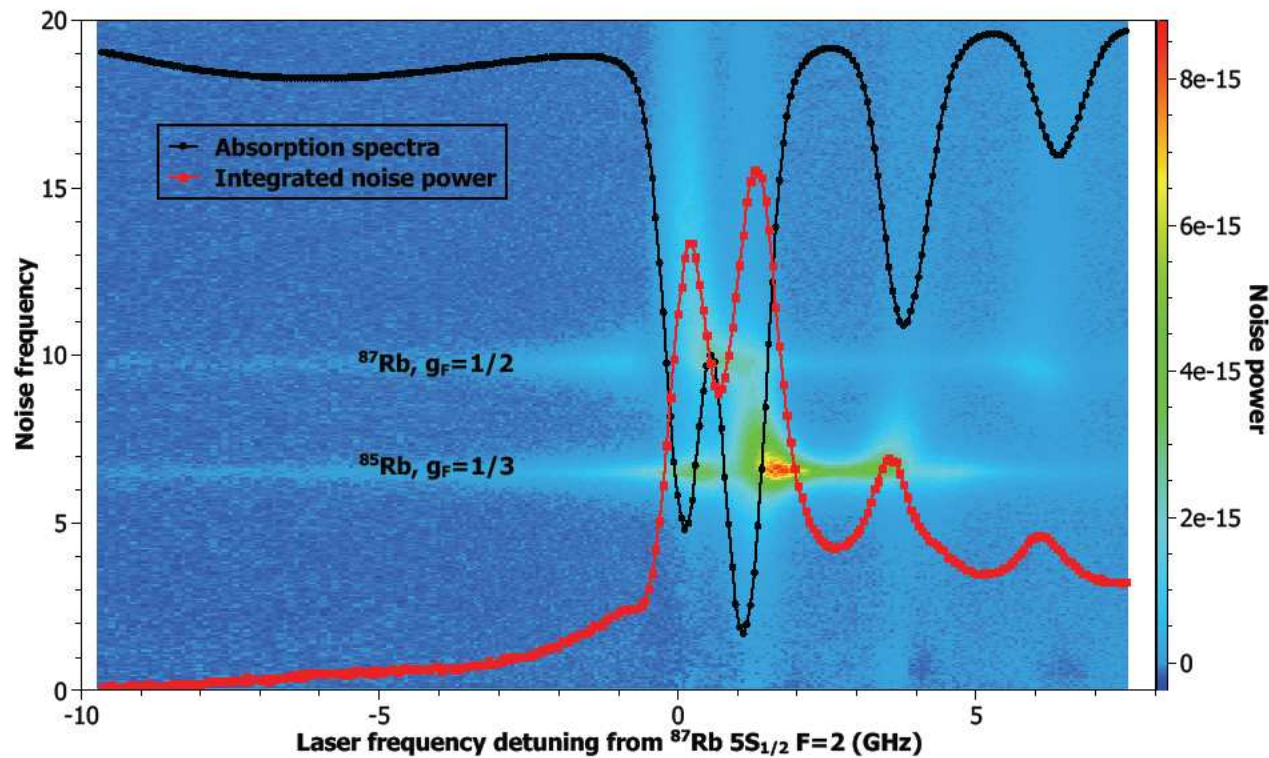
- Measurements on single donor atoms in GaAs
- Ultra long spin lifetimes in  $^{28}\text{Si}:\text{P}$



Poster by Hannes Bernien and Tammo Böntgen

# Spin noise in rubidium gas

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Poster by Hauke Horn

# Conclusion

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## Spin Noise Spectroscopy...

- is a very **sensitive technique**.
- allows to unravel the intrinsic spin dynamics which may have been masked by optical excitations.
- is nearly **perturbation free**.

### References:

M. Oestreich, et al., Phys. Rev. Lett. 95, 216603 (2005)

M. Römer, et al., Rev. Sci. Instrum. 78, 103903 (2007)

# Thank you for your attention!

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## References:

**M. Oestreich, et al., Phys. Rev. Lett 95, 216603 (2005)**

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