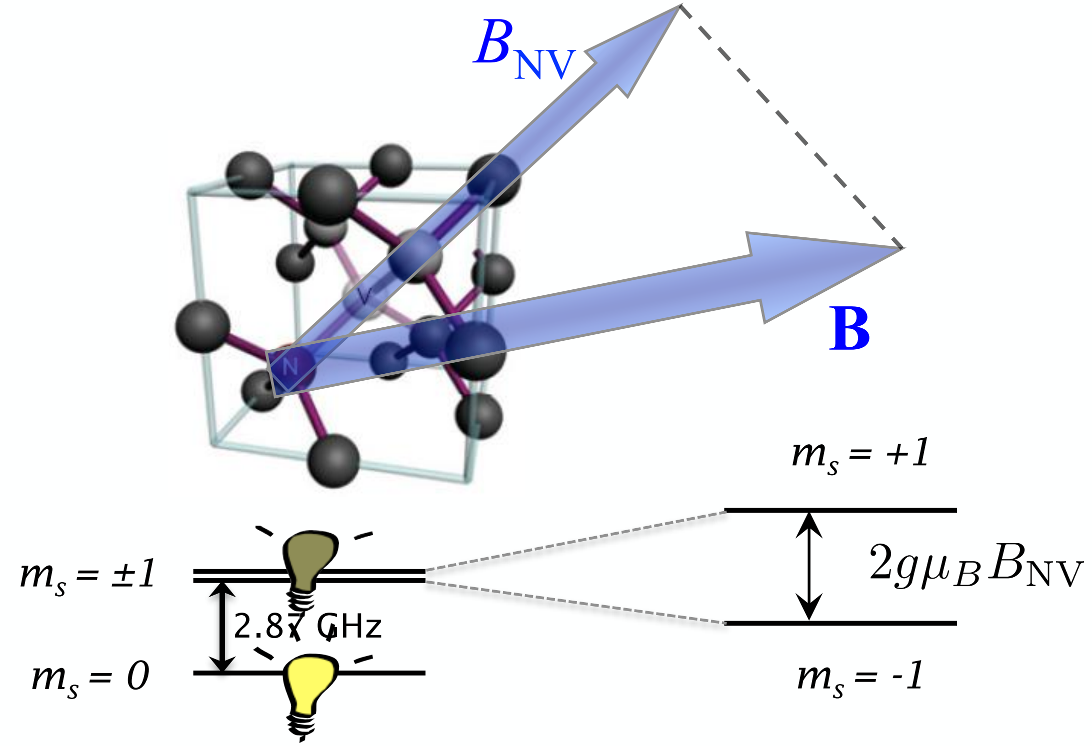
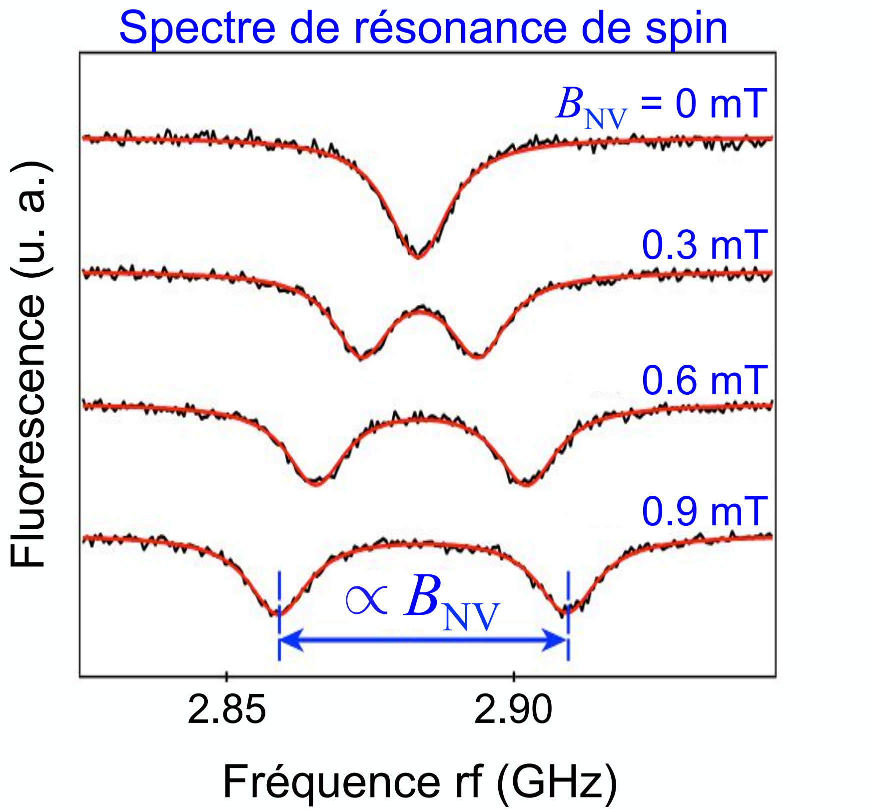
Sensitivity of magnetic sensing:
The influence of the environment

Influence of an external magnetic field





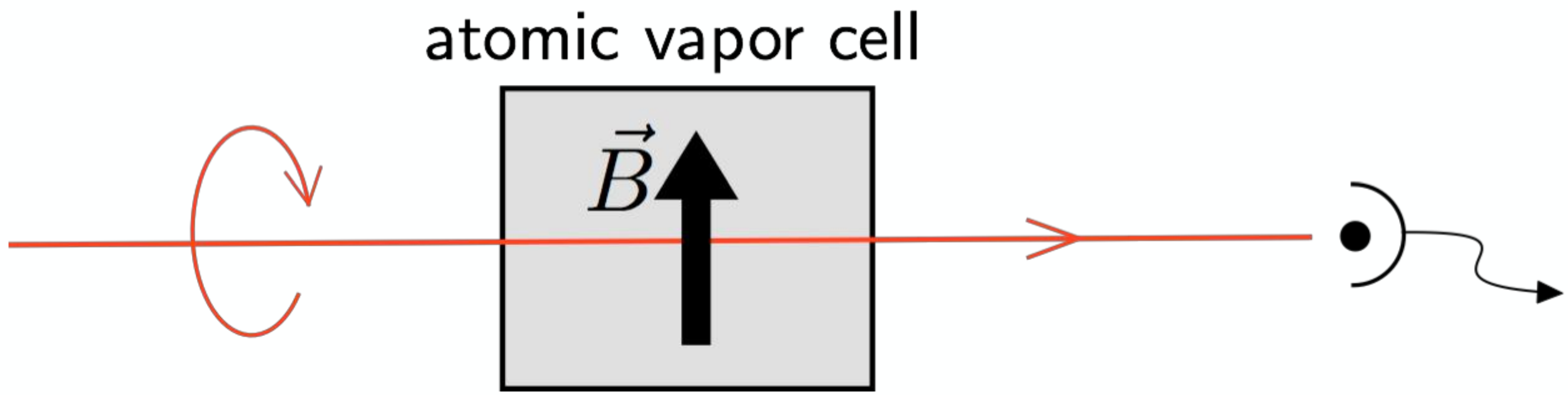
$$g_{\mathrm{NV}} = 2.0030 \quad (\text{for a single electron } g = 2.0023)$$

$$\longrightarrow \text{ Zeeman shift} \approx 28\,\mathrm{MHz/mT}$$

NV center $\equiv$ magnetometer of atomic size
with sensitivity to DC magnetic field $\approx \mu$T

Maze et al, Nature **455**, 644 (2008)
Balasubramanian et al, Nature **455**, 648 (2008)

Atomic magnetometry: sensitivity



- The atomic dipoles precess at the Larmor frequency associated to the magnetic field: $\Omega_L = \gamma B$
- Coupling with light induces changes in polarization and intensity
- Sensitivity is limited by spin projection noise:

$$\delta B_{\mathrm{SNL}} \approx \frac{1}{\sqrt{N}} \times \frac{1}{\sqrt{\Gamma_{\mathrm{spin}} \tau}} \times \frac{\Gamma_{\mathrm{spin}}}{\gamma} \quad \rightarrow \quad \delta B_{\mathrm{SNL}} \approx \frac{1}{\gamma} \sqrt{\frac{\Gamma_{\mathrm{spin}}}{N \tau}}$$

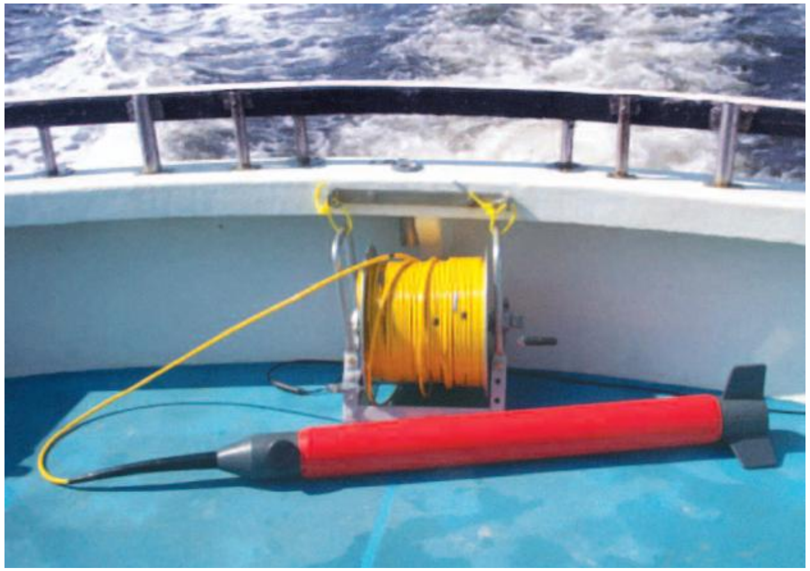
$$\left.\begin{array}{l} N = n_{\mathrm{at}} \times V \\ \Gamma_{\mathrm{spin}} = n_{\mathrm{at}} \times \xi \end{array}\right\} \quad \rightarrow \quad \delta B \approx \frac{1}{\gamma} \sqrt{\frac{\xi}{V \tau}}$$

"Optical Magnetometry", Budker & Jackson Kimball eds (Cambridge Univ. Press)

Magnetometry : atoms vs NV

$$\delta B \approx \frac{1}{\gamma}\sqrt{\frac{\xi}{V\tau}}$$

Very high sensitivity can be achieved by optimizing the relaxation rate or by increasing the volume



sensitivity $\simeq$ 10 pT/$\sqrt{\text{Hz}}$

record values $\simeq$ 0.01 fT/$\sqrt{\text{Hz}}$

photon shotnoise limit

$$\delta B \approx \frac{1}{\gamma_{\rm NV}} \times \frac{1}{C} \times \frac{1}{\sqrt{R} \times \sqrt{T_2^\star}}$$

$$\gamma_{\rm NV} = (2\pi) \times 28\,\text{MHz/mT}$$

C : ODMR contrast

$T_2^\star$: spin coherence time

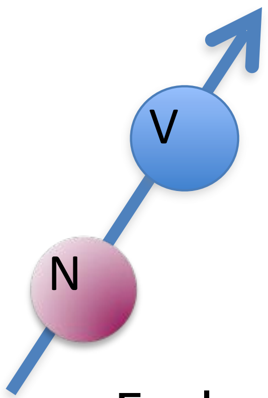
R : photon detection rate

$R \propto N_{\rm NV}$ number of NV centers

$R \propto \epsilon$ photon collection efficiency

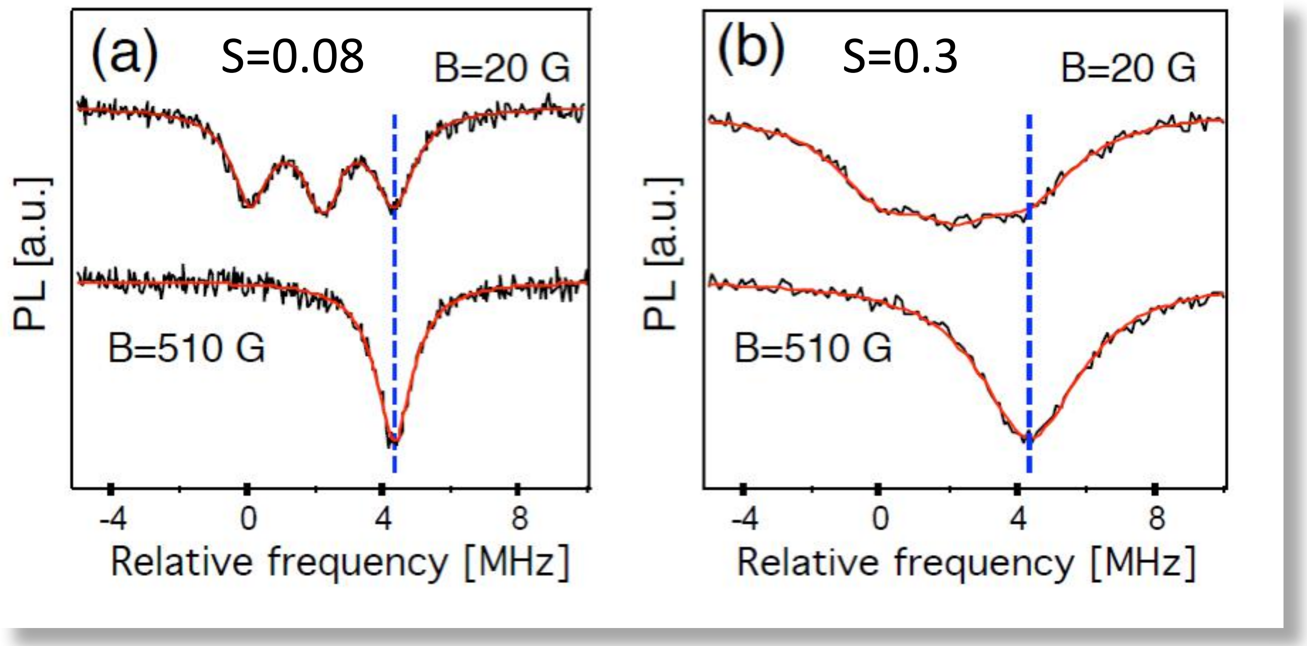
All parameters need to be optimized. It can provide both sensitivity and spatial resolution or field of view

Experimental results



^{14}N
nuclear spin I=1

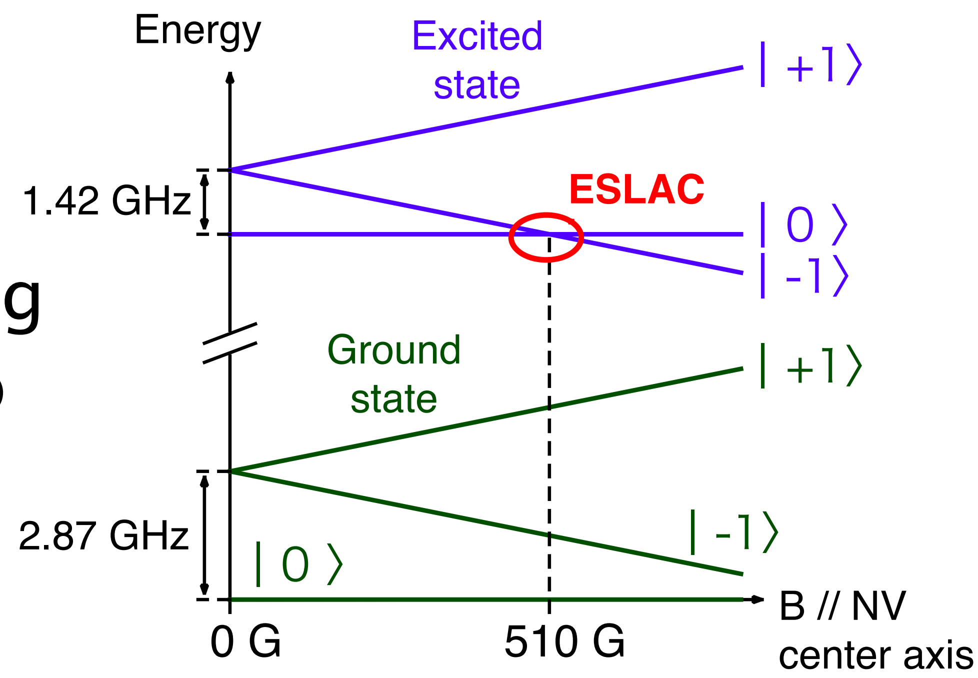
Each electron spin state splits into 3 sub-levels



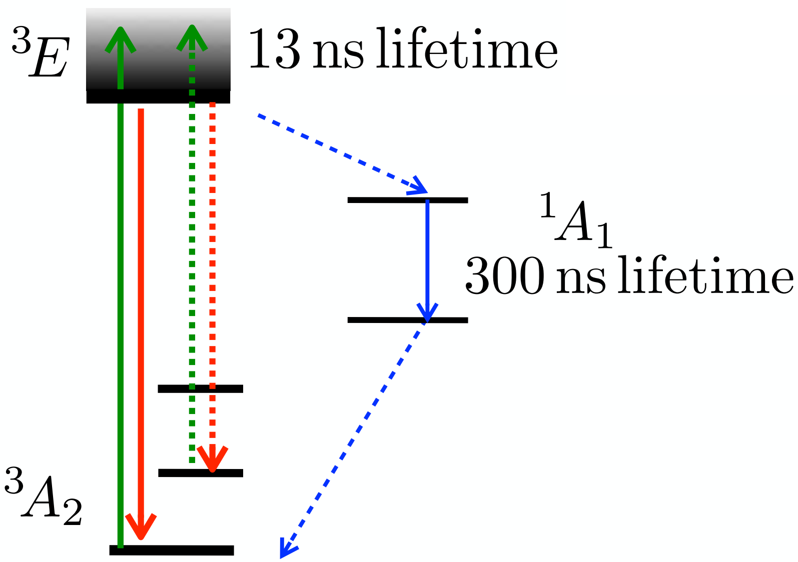
How to polarize the ^{14}N nuclear spin?

Excited State Level Anti-Crossing

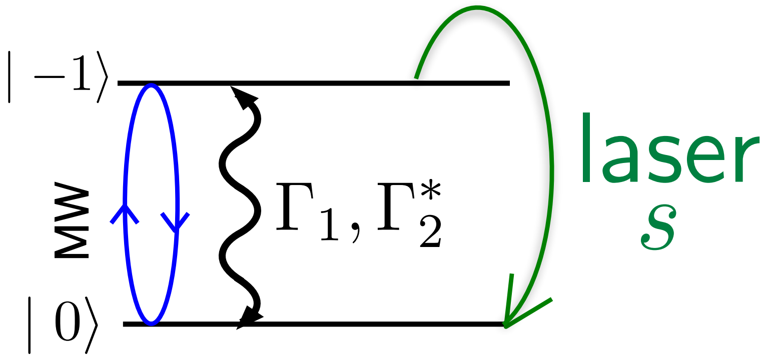
V. Jacques et al., Phys. Rev. Lett. 102, 057403 (2009)
A. Gali, Phys. Rev. B 80, 241204 (2009)



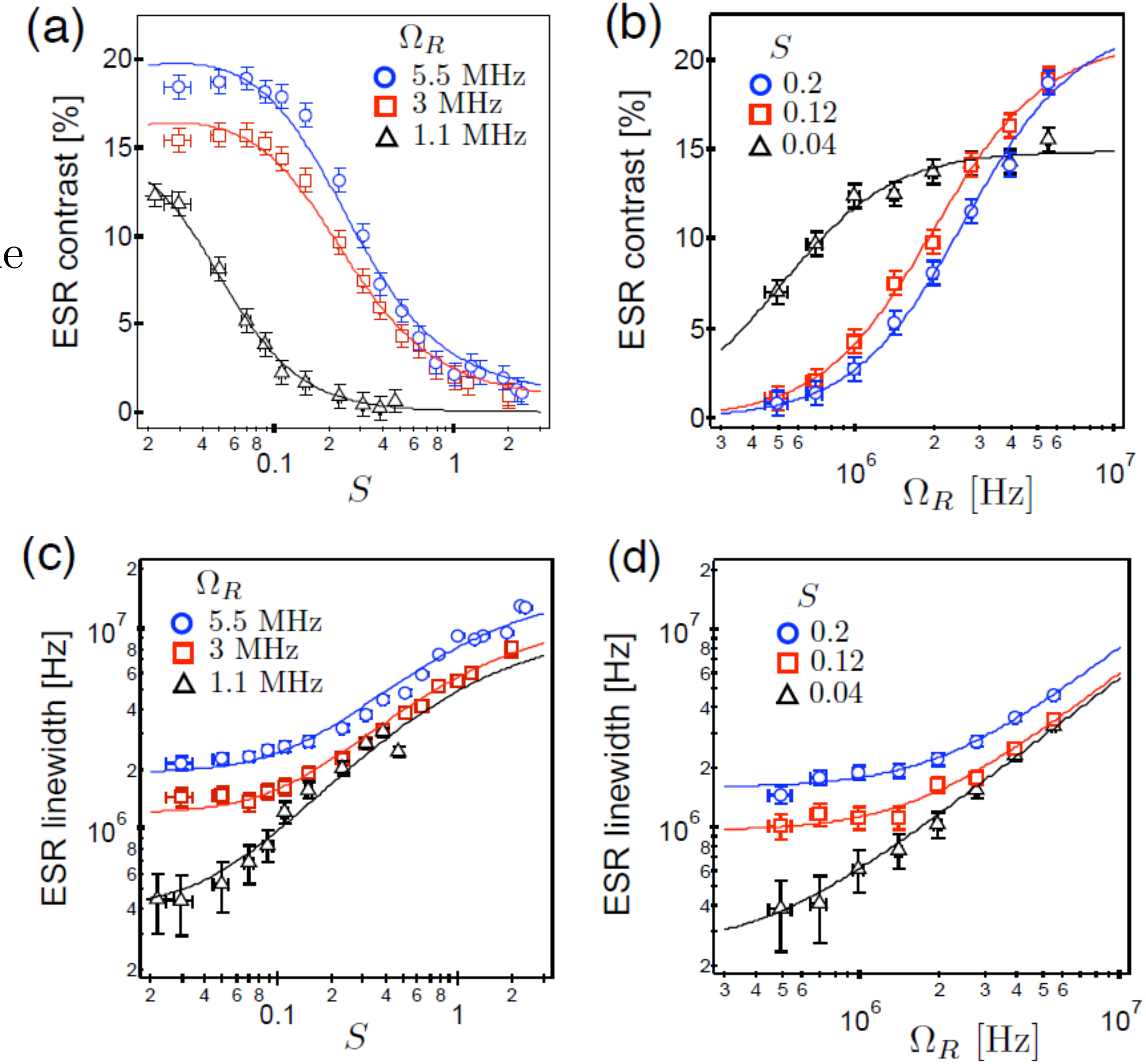
ODMR contrast and linewidth



simplified model



$$\Gamma_1 = 10^3\ \mathrm{s}^{-1}$$
$$\Gamma_2^* = 2 \times 10^5\ \mathrm{s}^{-1}$$

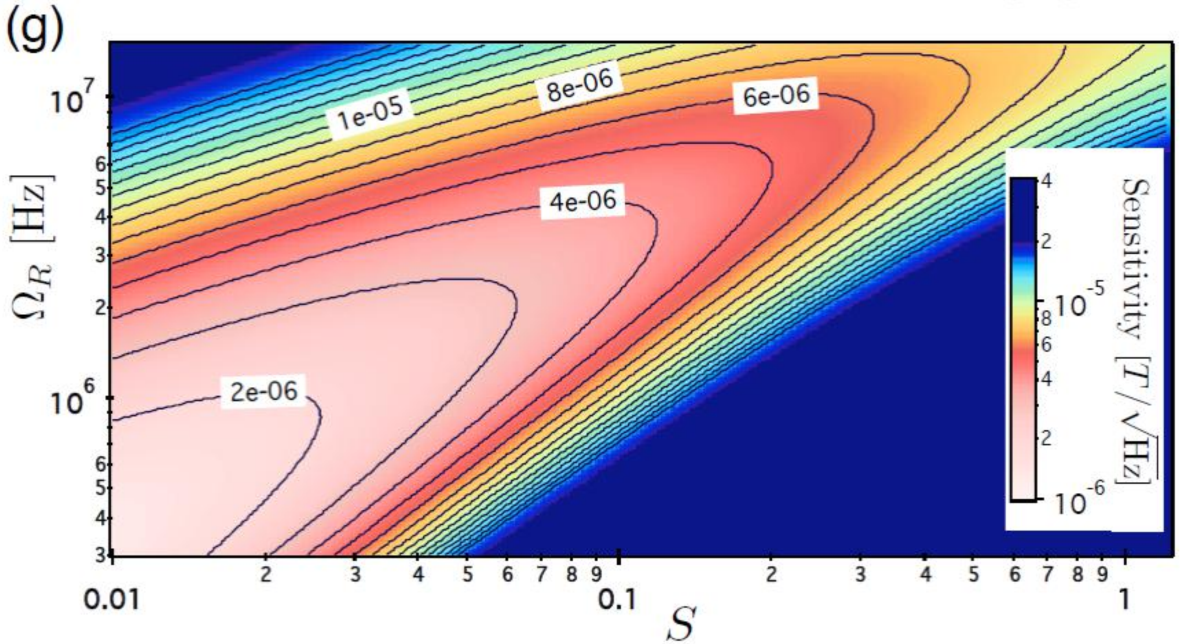


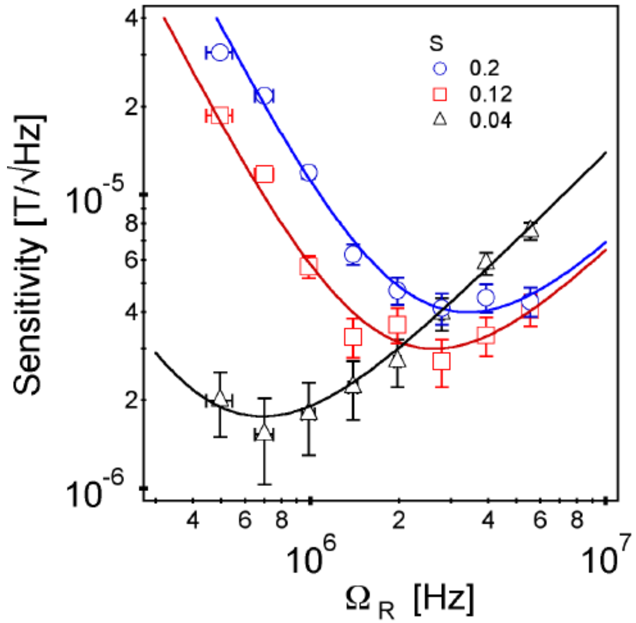
A. Dreau, M. Lesik, et al., Phys. Rev. B 84, 195204 (2011)

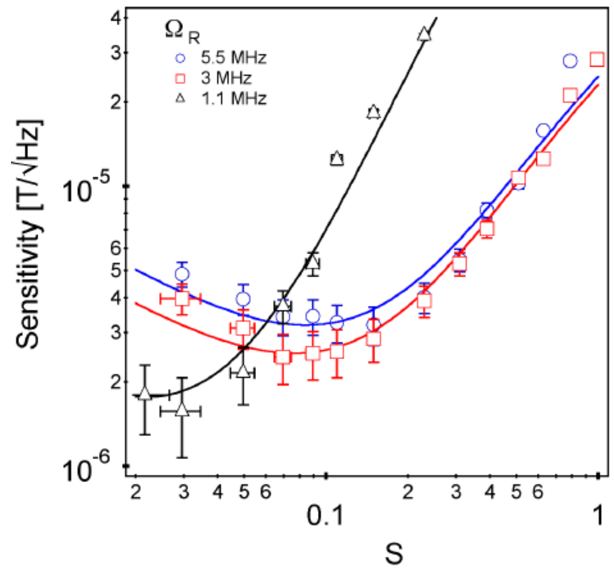
Magnetic field sensitivity (DC)

$$\eta\left[\frac{\mathsf{T}}{\sqrt{\mathsf{Hz}}}\right]=\frac{h}{g\,\mu_B}\,\frac{\Delta\nu}{C\,\sqrt{\mathcal{R}}}$$

$$\mathcal{R}=\mathcal{R}^{\infty}\frac{s}{1+s}\qquad \mathcal{R}^{\infty}=250\times10^{3}\,\mathsf{s}^{-1}$$







Optimum $\eta \simeq 2\,\mu\mathsf{T}/\sqrt{\mathsf{Hz}}$

A. Dreau, M. Lesik, et al., Phys. Rev. B 84, 195204 (2011)