Atomic Physics in high magnetic fields

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23/10/2015

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Outline

- Introduction
- Motivations
- High resolution spectroscopy in 0.05- 0.13 T magnetic field
- Spectroscopy in high magnetic fields
- Conclusions and perspectives

LNCMI

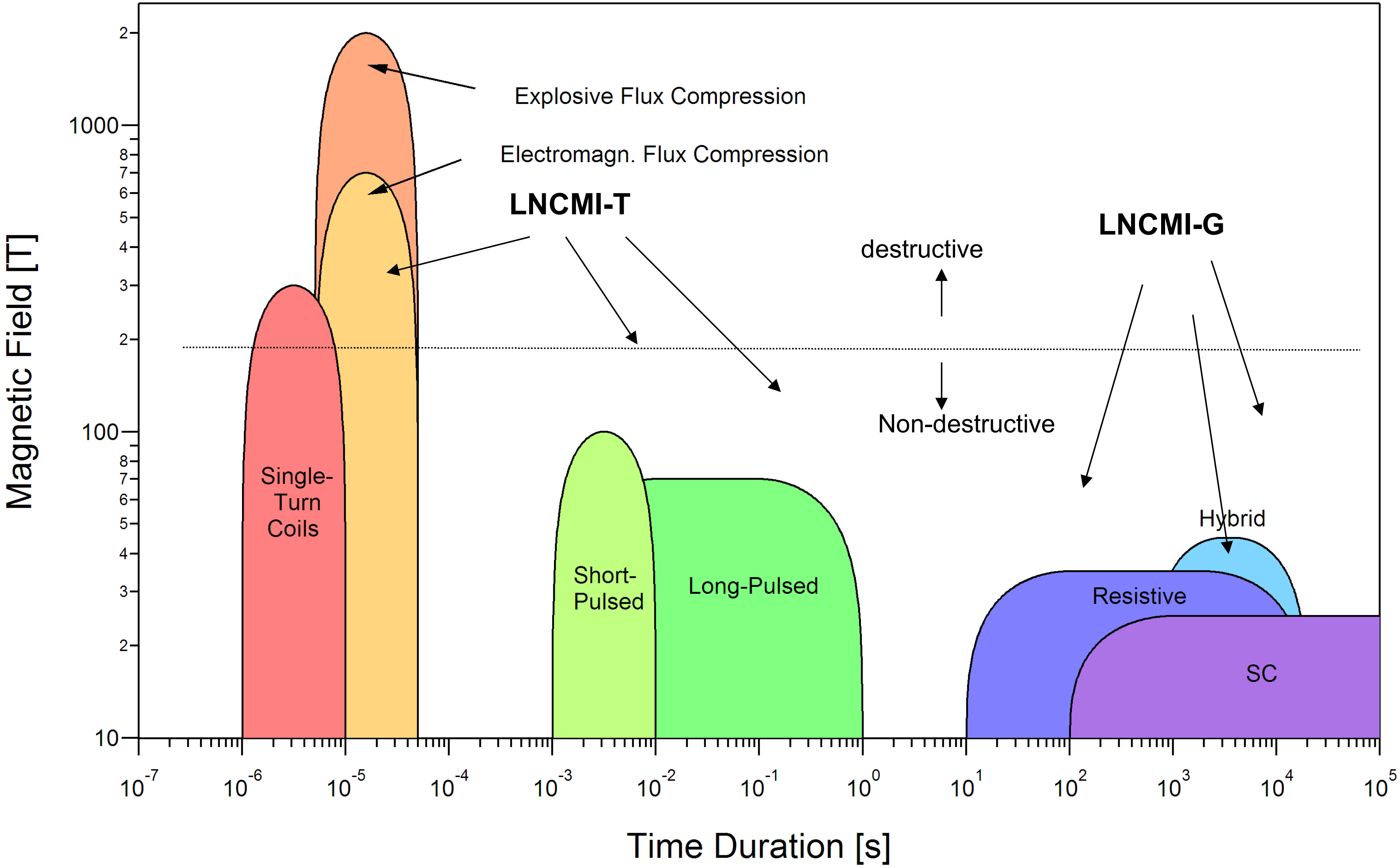
Laboratoire National des Champs Magnétiques Intenses

Grenoble
Static fields

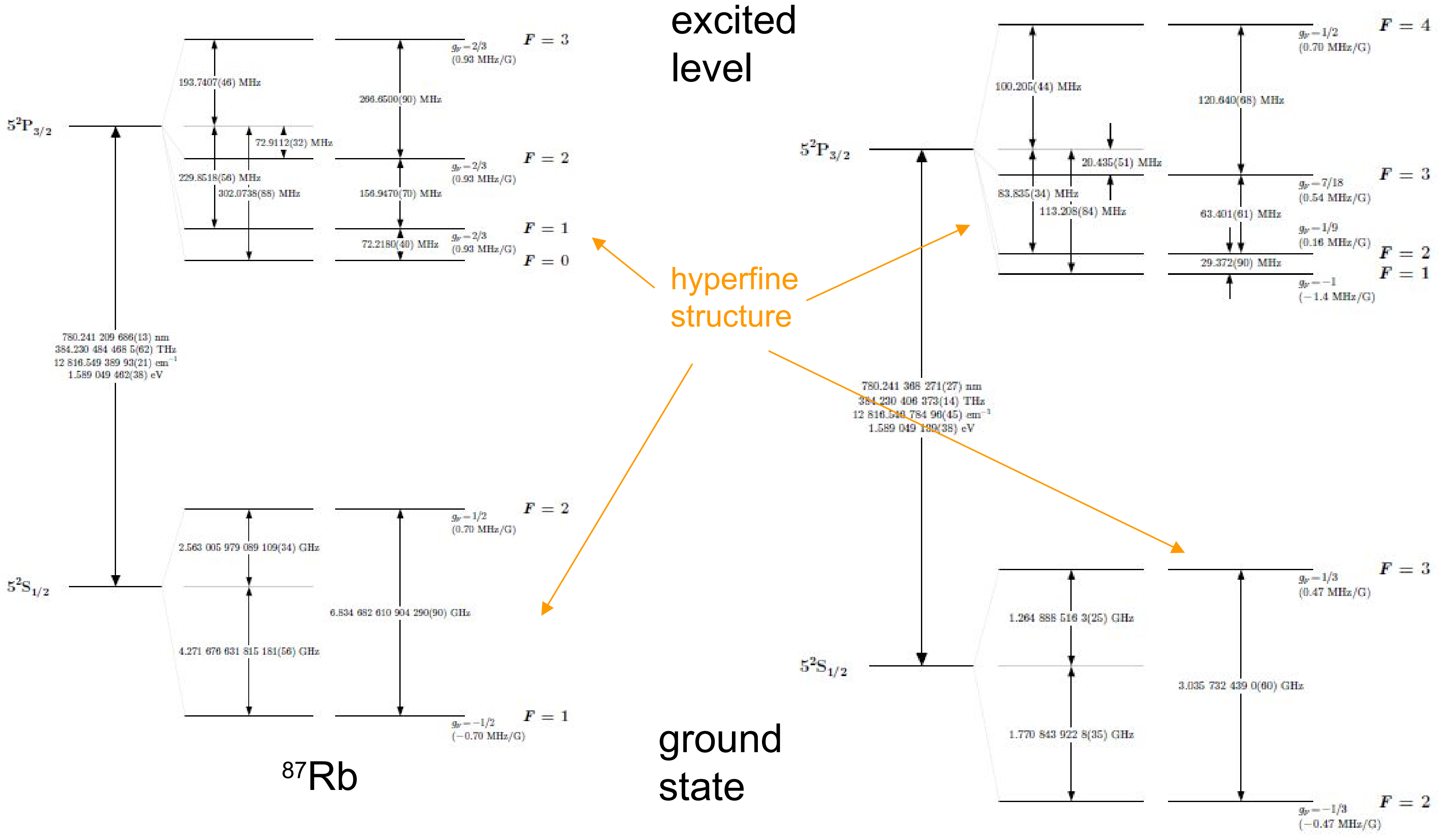
Toulouse
Pulsed fields

The ***Laboratoire National des Champs Magnétiques Intenses*** (LNCMI) is a large scale CNRS research facility in France, enabling researchers to perform experiments in the highest possible magnetic fields. Continuous fields are available at the Grenoble site (LNCMI-G) and pulsed fields at the Toulouse site (LNCMI-T).

Magnetic fields at LNCMI



Rubidium energy diagram



excited level

hyperfine structure

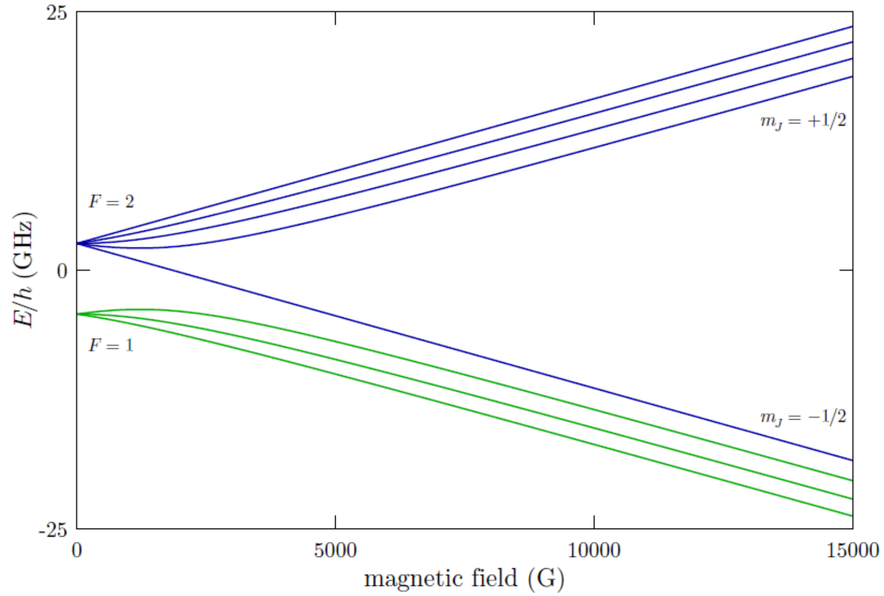
ground state

^{87}Rb

^{85}Rb

transition frequency : 384.2304844685(62) THz
transition wavelength : 780.244209686(13) nm

Ground state



^{87}Rb ground state in a magnetic field

Analytical Breit-Rabi formula

$$E_{|J=1/2\, m_J\, I\, m_I\rangle} = -\frac{\Delta E_{\mathrm{hfs}}}{2(2I+1)} + g_I\, \mu_{\mathrm{B}}\, m\, B \pm \frac{\Delta E_{\mathrm{hfs}}}{2}\left(1 + \frac{4mx}{2I+1} + x^2\right)^{1/2}$$

with

$$x = \frac{(g_J - g_I)\mu_{\mathrm{B}}\, B}{\Delta E_{\mathrm{hfs}}}$$

$$m = m_I \pm m_J$$

ΔE_{hfs}/h = ½ x 3.417341305452145(45) GHz

Landé g-factors

g_j^g = 2.002331113(20)

g_i^g = -0.0009951414(10)

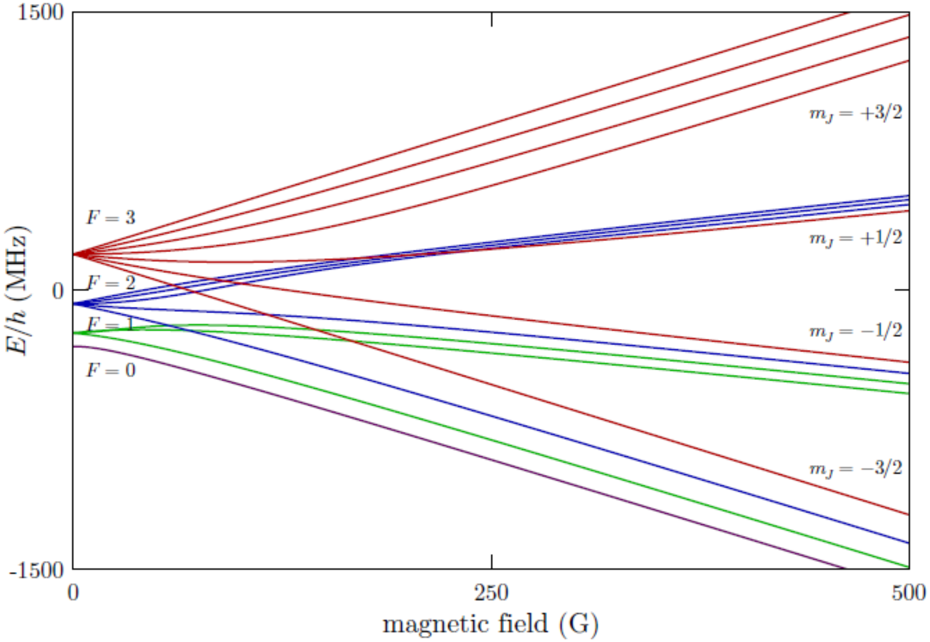
μ_B/h = 13.99624604(35) GHz/T

Ideal for field metrology : sensitivity of a few 10^{-15} T/Hz$^{-1/2}$

see e.g.: *Optical magnetometry*
Budker & Kimball eds.
Cambridge university press

$5P_{3/2}$ excited state

^{87}Rb excited level
in a magnetic field



No analytical formula exists, thus one has to calculate numerically the energy of every level using standard quantum mechanics

g_j^e = 1.3362(13) measured
g_j^e = 1.33411 theoretical

QED correction expected at 10^{-5}-10^{-6} level

Arimondo et al., RMP, 1977
Flaumbaum et al.,PRA, 2013
Steck, Rubidium 87 D Line Data, 2010

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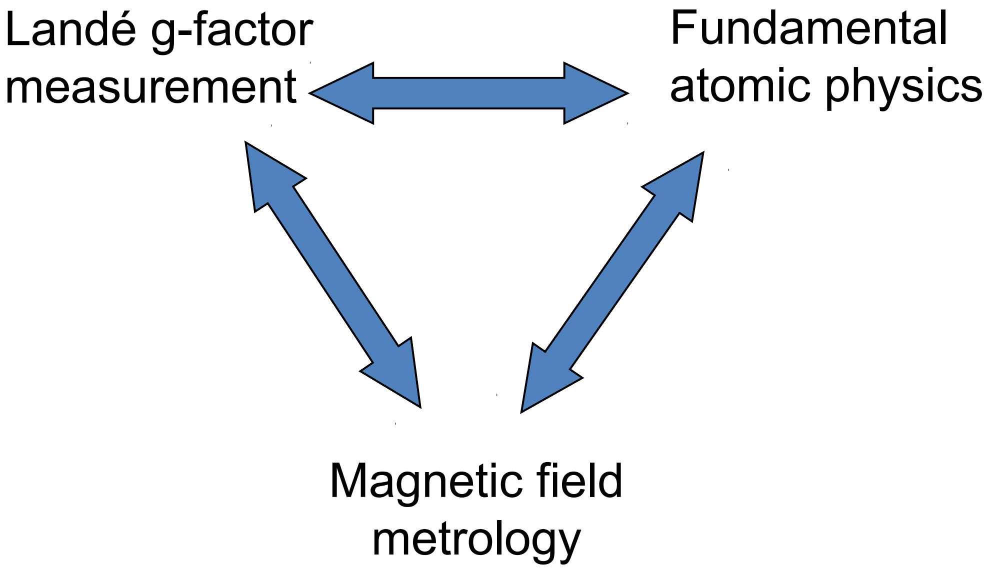
RUbidium in High MAgnetic field : RUHMA

Funded by NEXT

Collaboration between BMV group
(LNCMI- Toulouse)
& BEC Group of Dep. of Physics,
University of Pisa, Italy



Landé g-factor measurement

Fundamental atomic physics

Magnetic field metrology

Goal :

- **Precise measure of Landé factor**
- **Calibration of strong pulsed and stationary magnetic fields**

G. H. Gossel, V. A. Dzuba, V. V. Flambaum, Phys. Rev. A 88, 034501 (2013)

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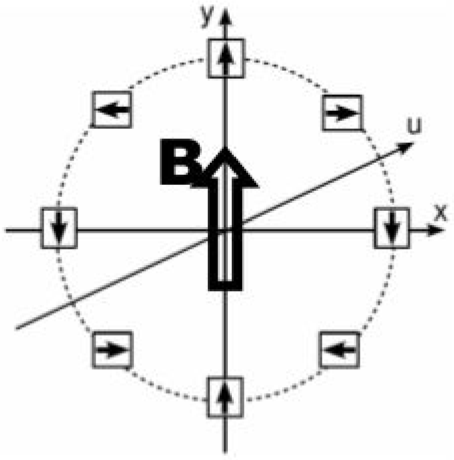
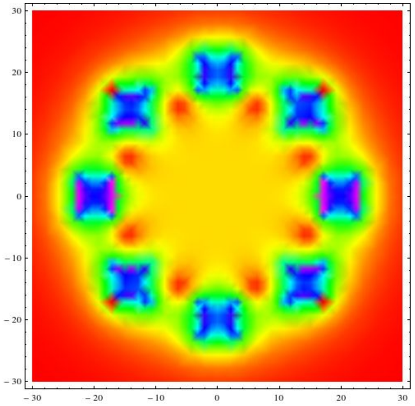
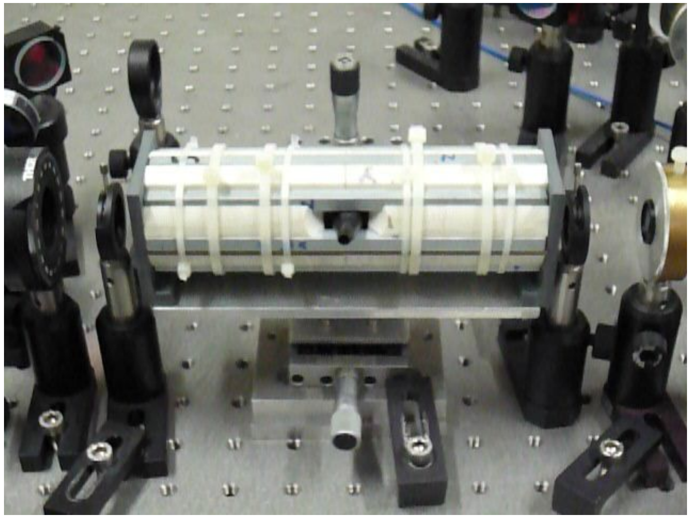
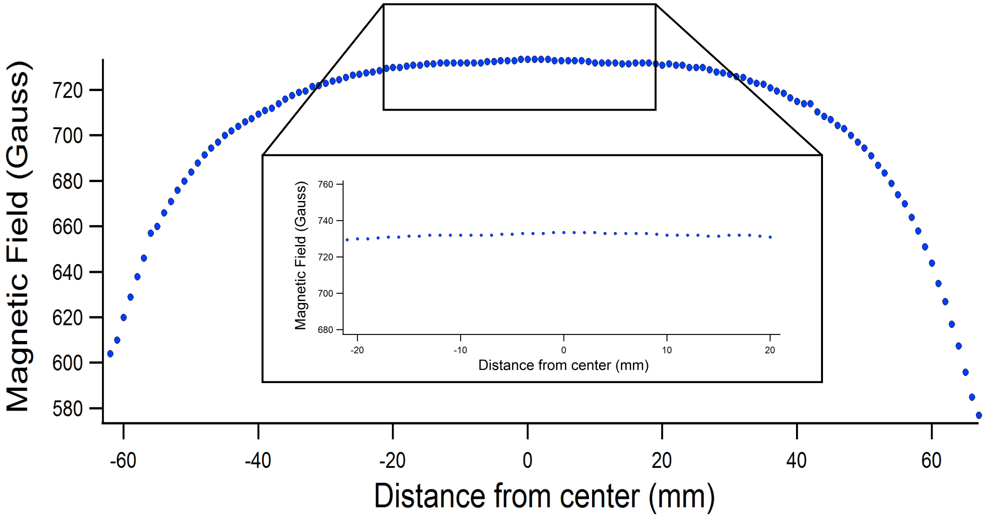
Halbach magnet



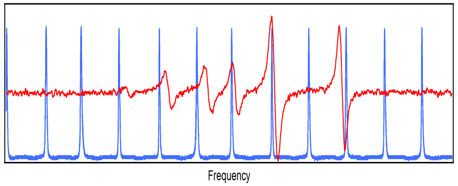


- •Eight NdFeB bar (148mmx6mmx6mm) flux density on surface 3200 G, remnant field 1.08 T
- •Three samples realized (B=550 G, 720 G, 1250 G)
- •Good homogeneity at the center

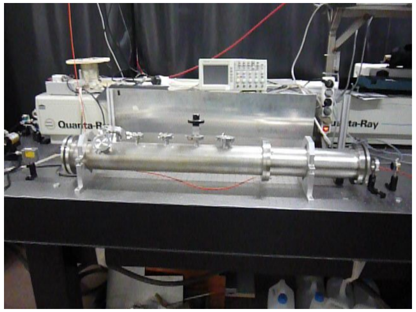


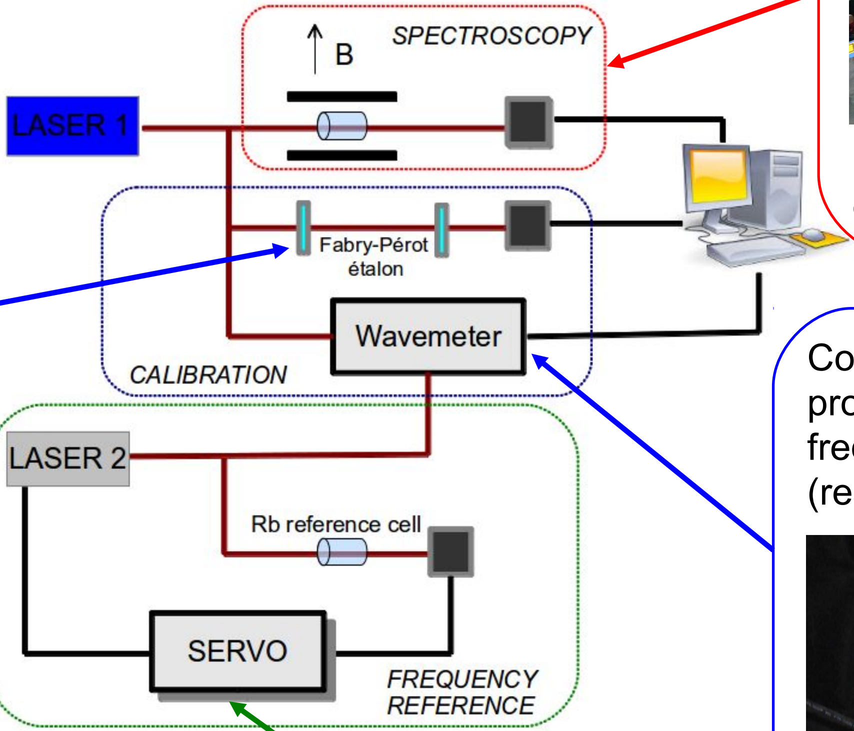


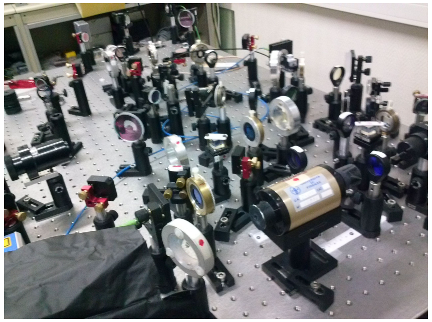
Experimental scheme



Homemade frequency étalon gives a relative frequency reference
(mode spacing ~ 75 MHz)

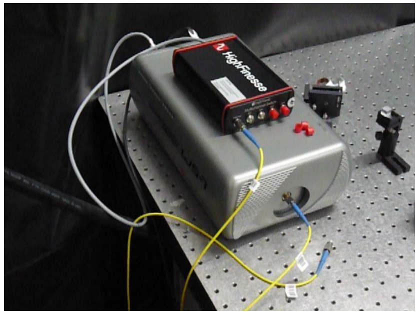






Doppler-free spectroscopy of Rb in a magnetic field

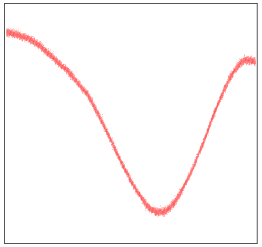
Commercial wavemeter provides a precise frequency measurement (resolution 0.5 MHz)



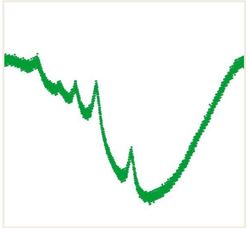
Laser locked on B=0 spectroscopy on Rb to calibrate wavemeter

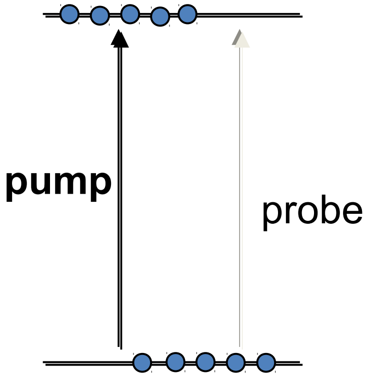
Sub-Doppler spectroscopy

Thermal motion cause line broadening due to Doppler effect

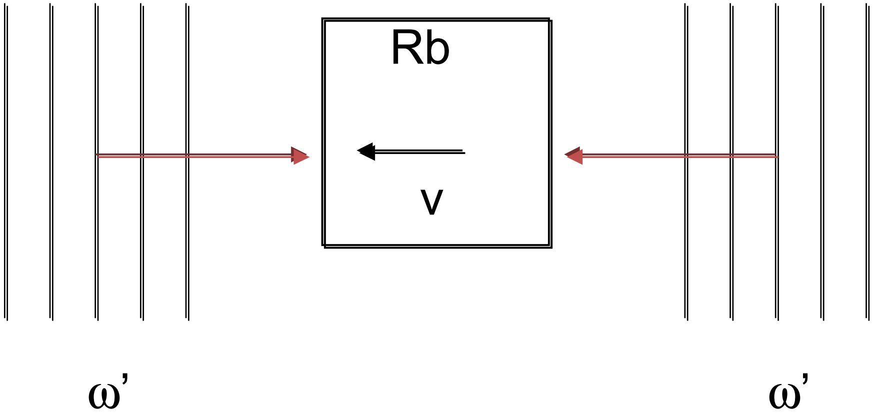


Two counterpropagating laser beams to select only atoms ''at rest'' : saturated absorption





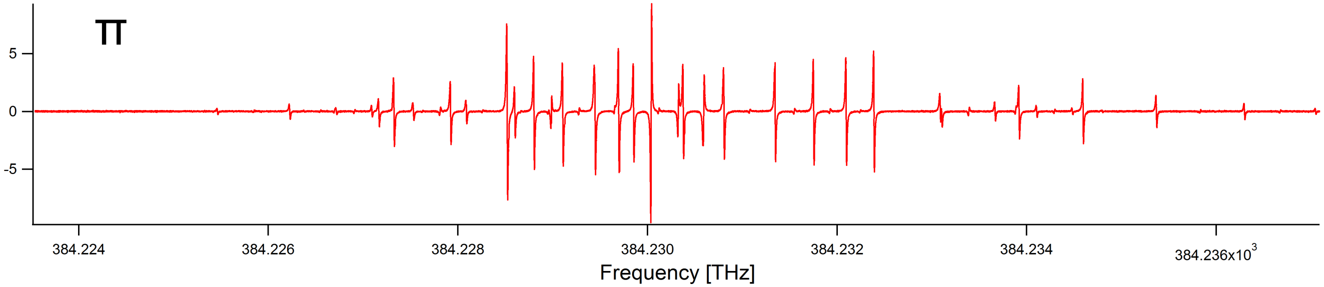
Pump beam saturates the transition

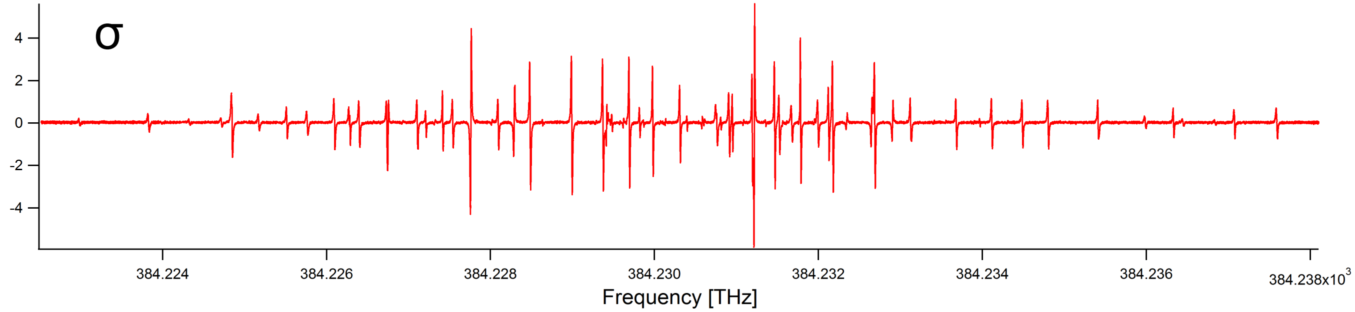


Probe beam is therefore less absorbed than in the configuration without pump beam

Spectra analysis

B=1250 G





•Identification of all transitions

•Comparison with numerical calculations

Zeeman/Paschen-Back intermediate regime

$g\mu_B B$ << hyperfine structure → Zeeman effect → $|J, F, m_F>$

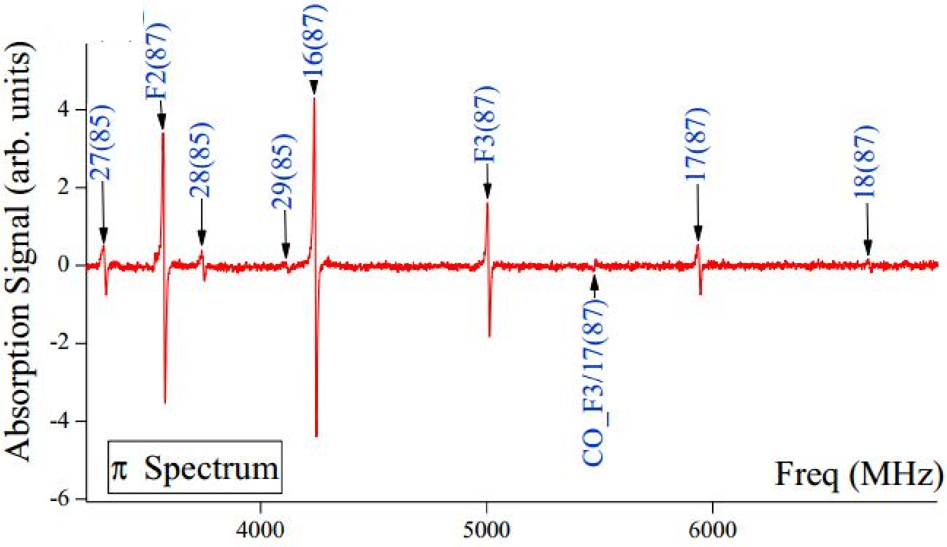
$g\mu_B B$ >> hyperfine structure → Paschen-Back effect → $|J, m_J, m_I>$

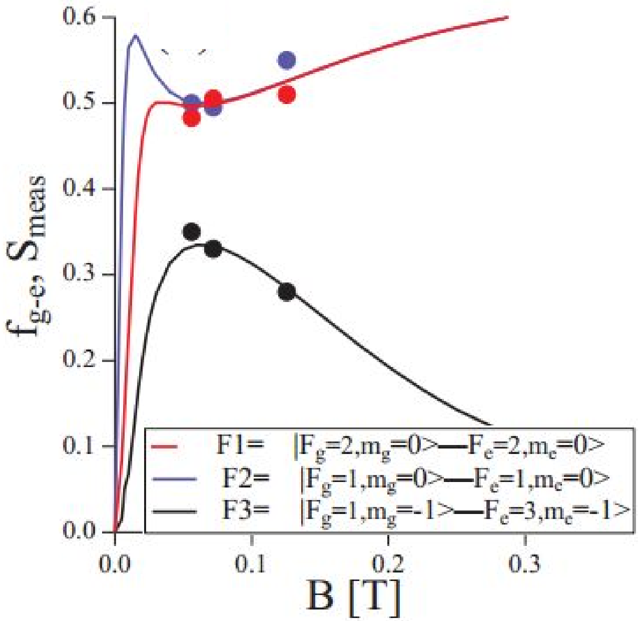
In the middle?

Angular momentum states are mixed

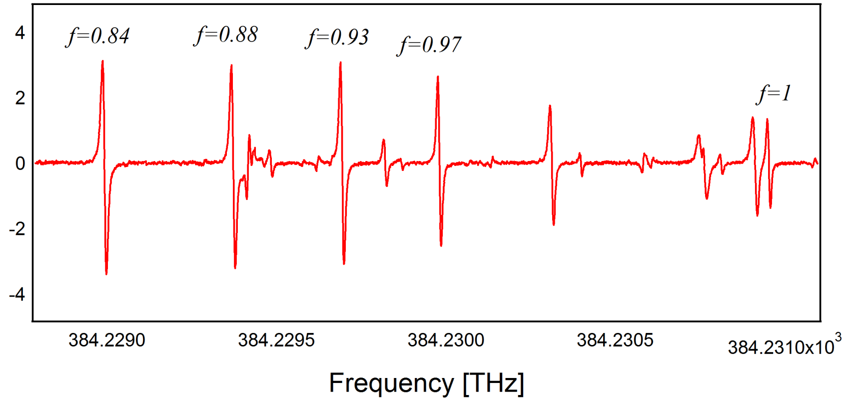
Selection rules are not valid

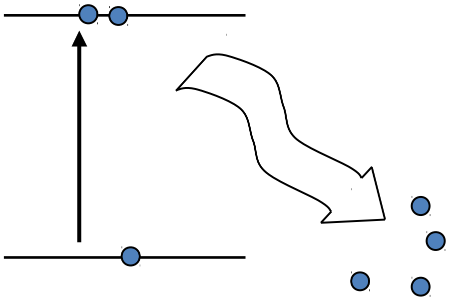
Forbidden transitions become allowed

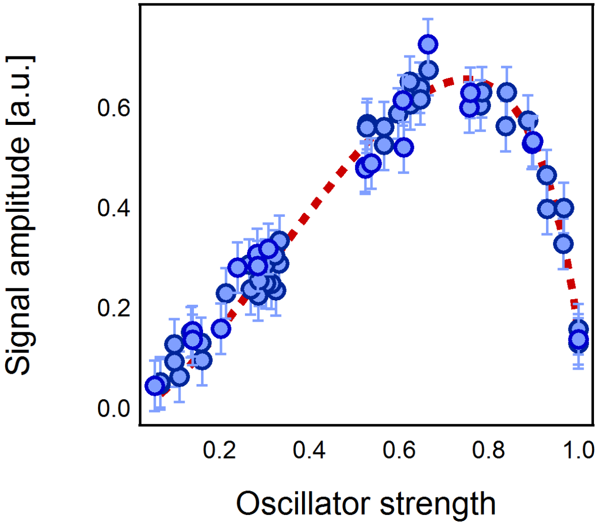




Open two level systems





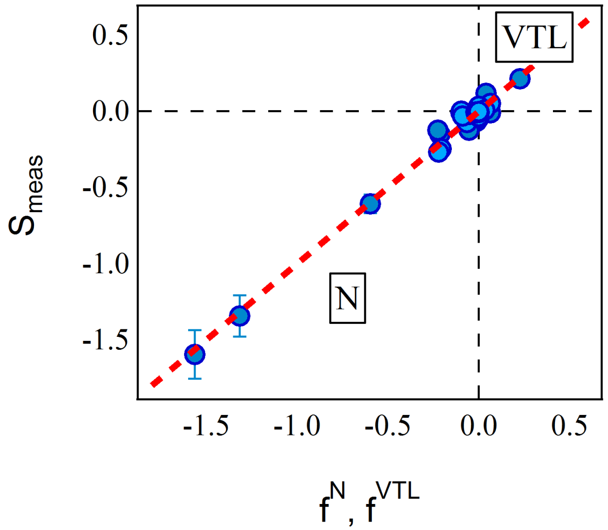


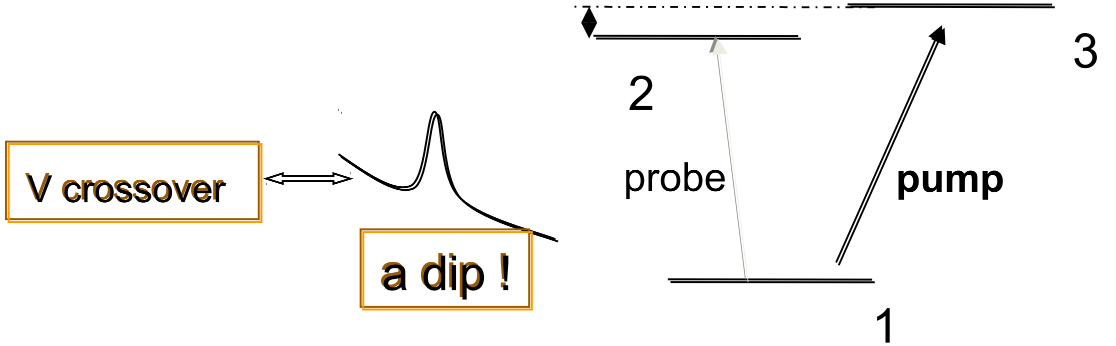
Optical pumping towards other states enhances de-population of lower state

⇩

Reduction of probe beam absorption

Three and four level cross-overs

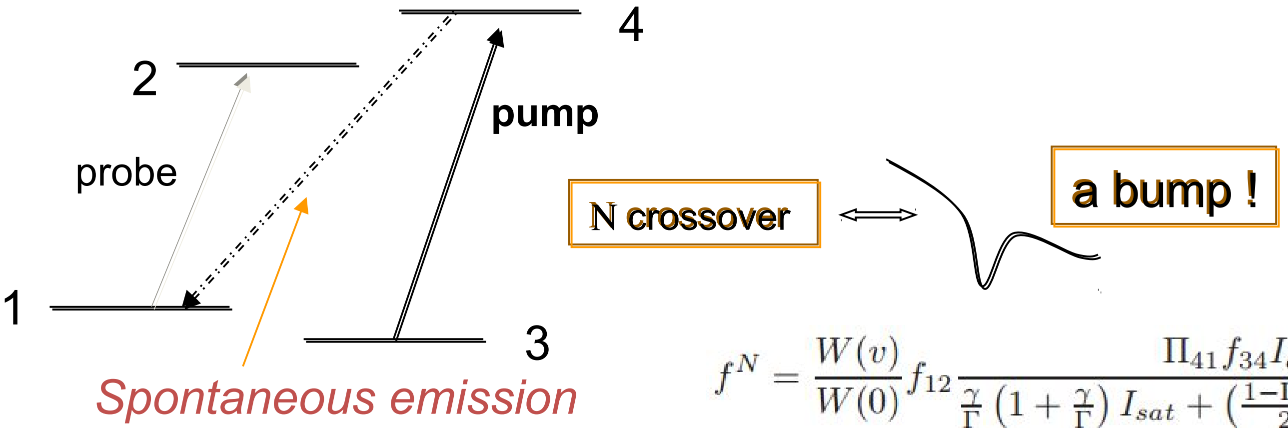




V crossover

a dip !

$$f^{VTL} = -\frac{W(v)}{W(0)} f_{12} \frac{\left(1+\frac{\Gamma}{\gamma}(1-\Pi_{31})\right) f_{13} I_c}{\left(1+\frac{\gamma}{\Gamma}\right) I_{sat} + \left(1+\frac{\Gamma}{\gamma}\frac{1-\Pi_{31}}{2}\right) f_{13} I_c}$$



N crossover

a bump !

$$f^N = \frac{W(v)}{W(0)} f_{12} \frac{\Pi_{41} f_{34} I_c}{\frac{\gamma}{\Gamma}\left(1+\frac{\gamma}{\Gamma}\right) I_{sat} + \left(\frac{1-\Pi_{43}}{2} + \frac{\gamma}{\Gamma}\right) f_{34} I_c}$$

S. Scotto *et al.* arXiv:1509.06978

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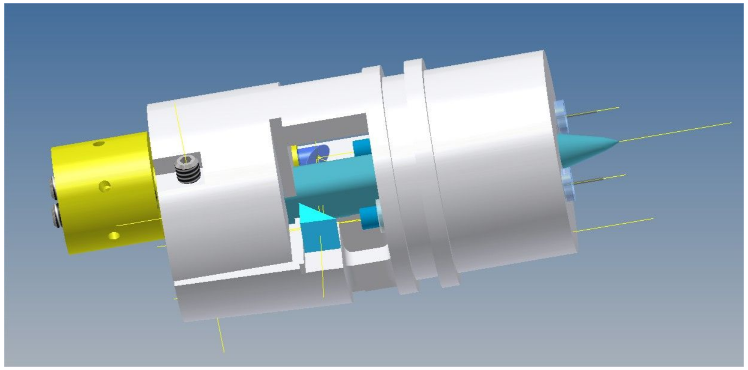
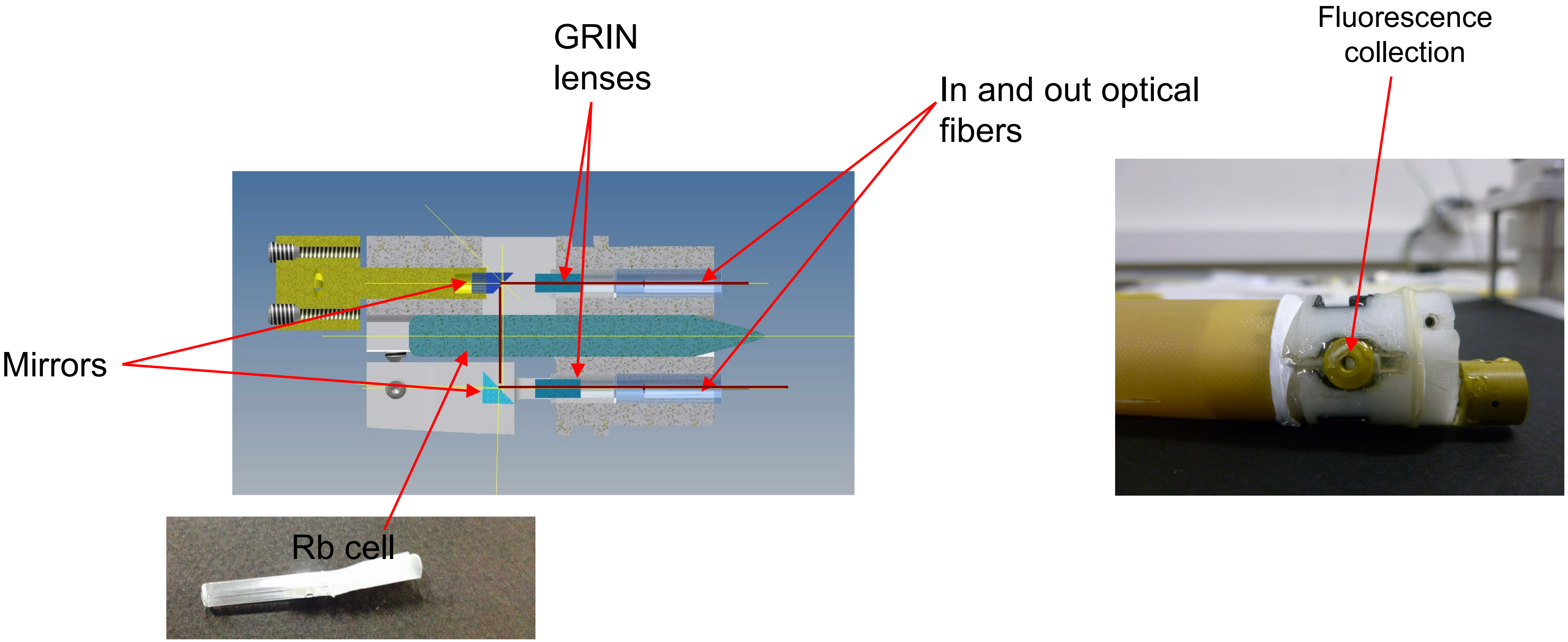
Mini-cell



Absorption and fluorescence in a 3 mm vapor cell



GRIN lenses

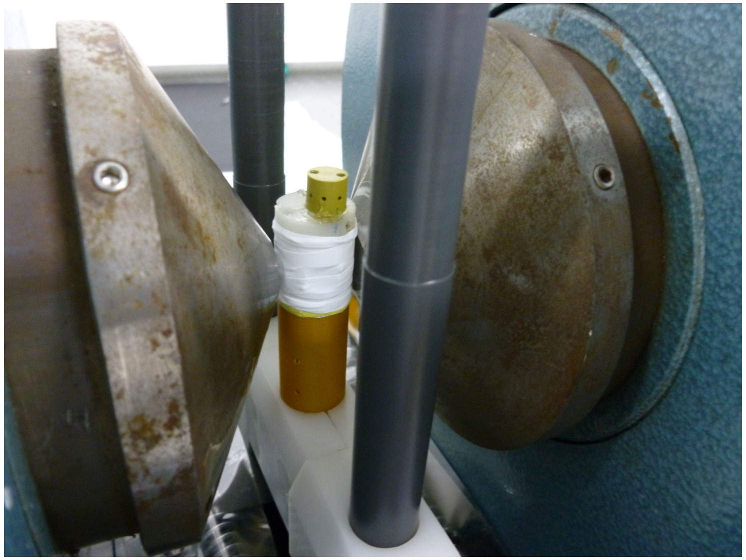
In and out optical fibers

Fluorescence collection

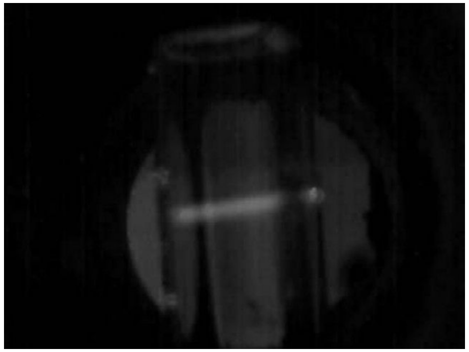
Mirrors

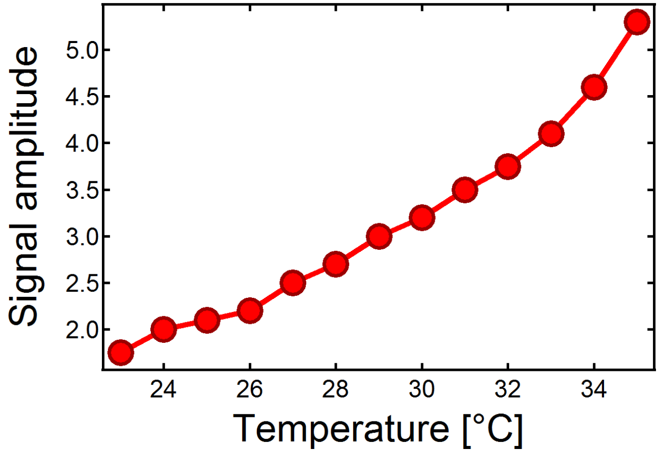
Rb cell

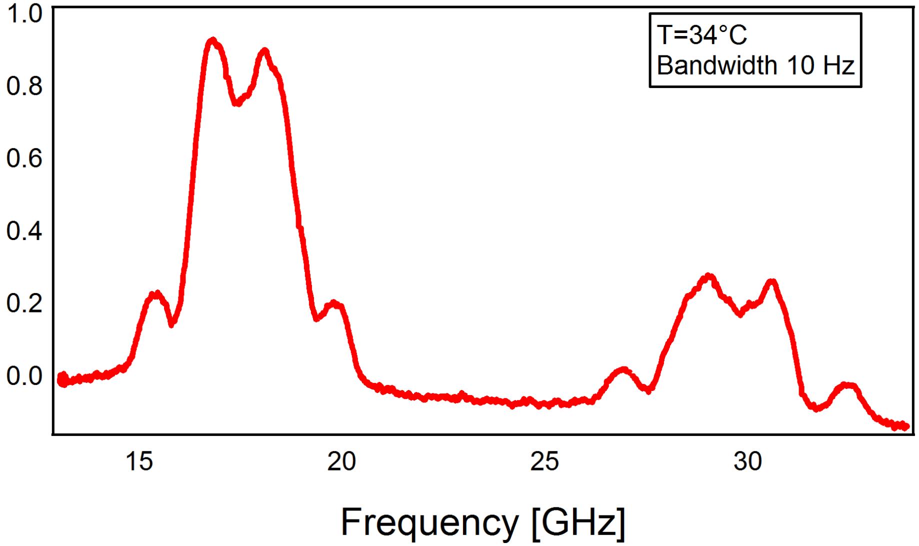
Preliminary tests



Fluorescence signal in an electromagnet @ 1.26 T







Perspectives

- New mini-cell prototype with improved signal to noise ratio
- Paschen-Back effect on D1 and D2 lines at 60 T
- Pulsed magnetic field measurements
- Test of bound state QED at $10^{-4} – 10^{-6}$
- Absolute measurement of magnetic field complementary to NMR

THANK YOU
FOR YOUR ATTENTION