

Unveiling the mechanism for nuclear spin self-orientation in ^3He gas discharges

1 - **Polarised ^3He** : Applications, polarisation methods

“Optically polarized ^3He ”, Rev. Mod. Phys. 89 (2017) 045004

2 - The **Polarised helium and quantum fluids** group at LKB

Expertise:

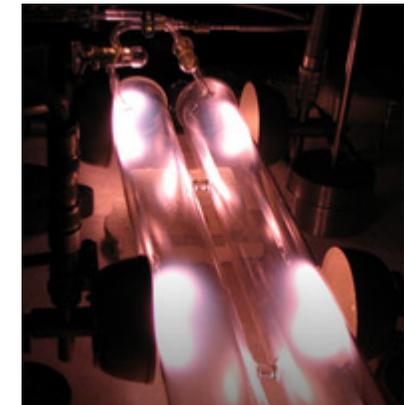
- Laser optical pumping, MEOP (>80% nuclear polarisation in ^3He)
- NMR & MRI in hyperpolarized systems (low or high field, liquid or gas).

Current activities, projects:

- Unconventional NMR/MRI techniques: low field (3-6 mT)
- **MARGIN**, 2020-22, **Magn. Reson. studies of Gas diffusion In Nanoporous materials**
- **HELPING**, 2021-25, **High-field Enhancement of nuclear Polarisation In Noble Gases**

3 - **Internship Project and PhD topics**

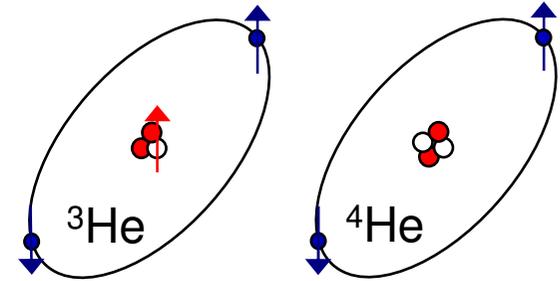
Polarization of Atoms in a Magnetized Plasma



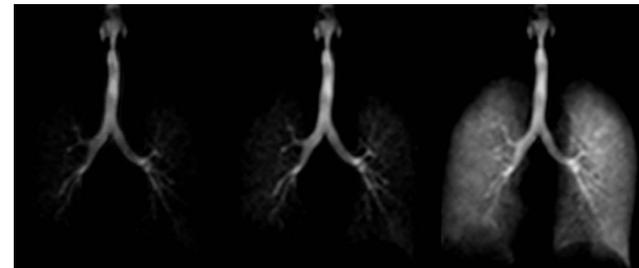
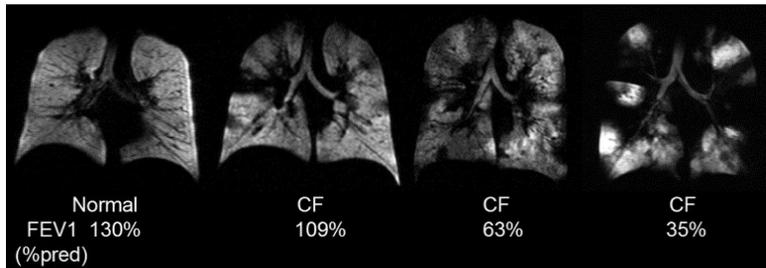
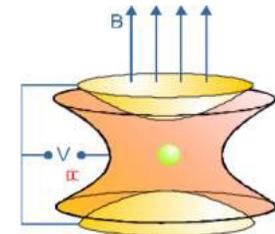
1 - Polarised ^3He : Applications, polarisation methods

^3He has a nuclear spin $I=1/2$

- Quantum statistics of a Fermion (at low T)
- Polarised nucleus \approx polarised (bound) neutron
 - neutron spin filter / polariser
 - high-energy physics, with ^3He ion beams or targets
 - Searches for axionlike interactions
- Nuclear magnetic moment
 - nuclear magnetometers, $\text{dB}/B \approx 10^{-12}$ in-situ **comagnetometer**
 - NMR and MRI, static and dynamic lung MRI



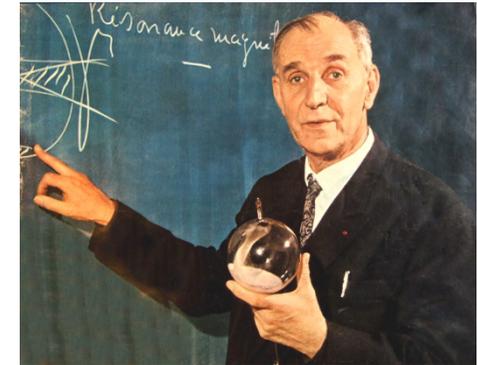
The PENTATAP project
Ion mass
measurements



1 - Polarised ^3He : Applications, polarisation methods

Optical pumping (OP) is the redistribution of atoms among the energy sublevels of the ground state by resonant absorption of light (out of thermal equilibrium). (A. Kastler, *Physica* 17,191,1951)

NB: at thermal equilibrium $\mu B \ll kT$: polarisation $P_{\text{He}} \approx 3 \times 10^{-6}$ for 1T, 300K

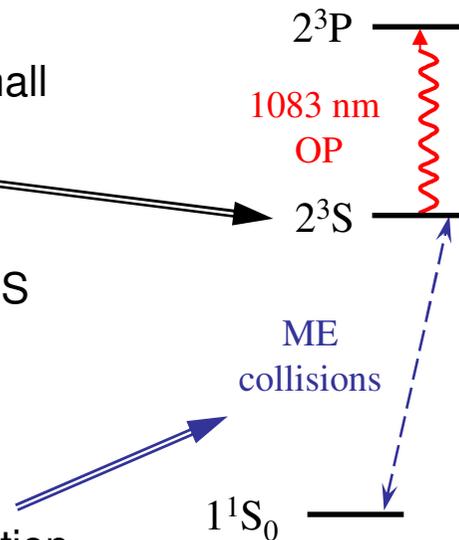


Metastability-Exchange Optical pumping (MEOP) of ^3He

- A weak rf discharge promotes a small fraction (10^{-6}) of the atoms into the excited metastable state 2^3S

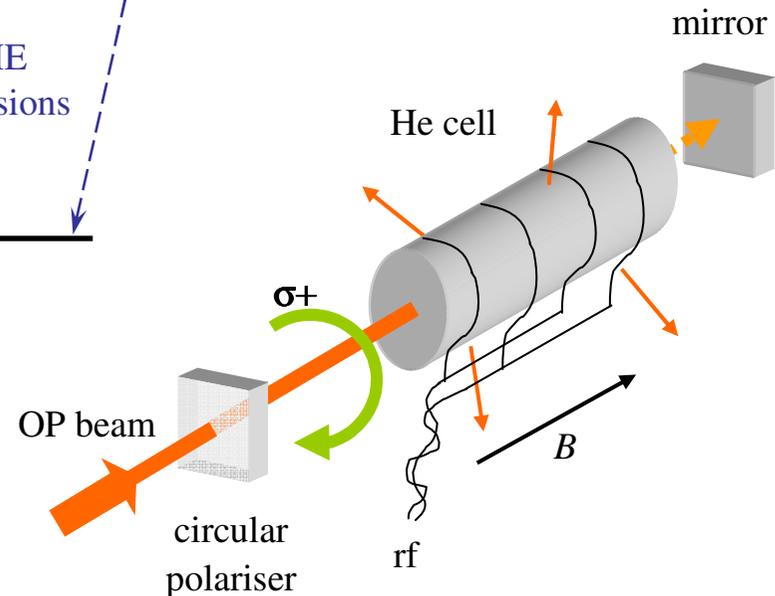
- S and I strongly entangled in the 2^3S state by hyperfine coupling: **OP simultaneously creates electronic and nuclear orientation**

- **ME collisions** (a very short interaction between a 2^3S state atom and a ground state atom), induce a **fast exchange of electronic excitations** with no loss of total angular momentum.



Two key processes:

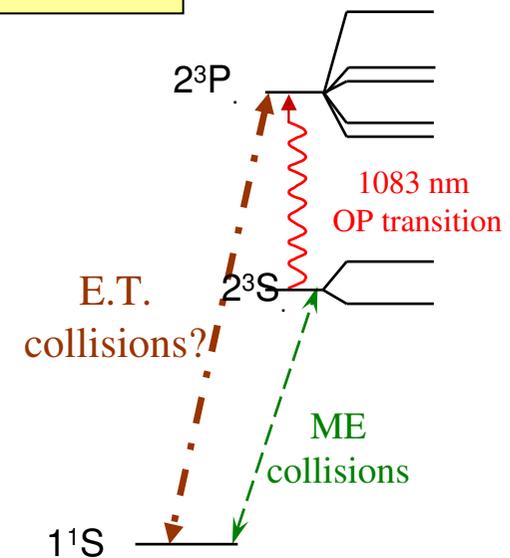
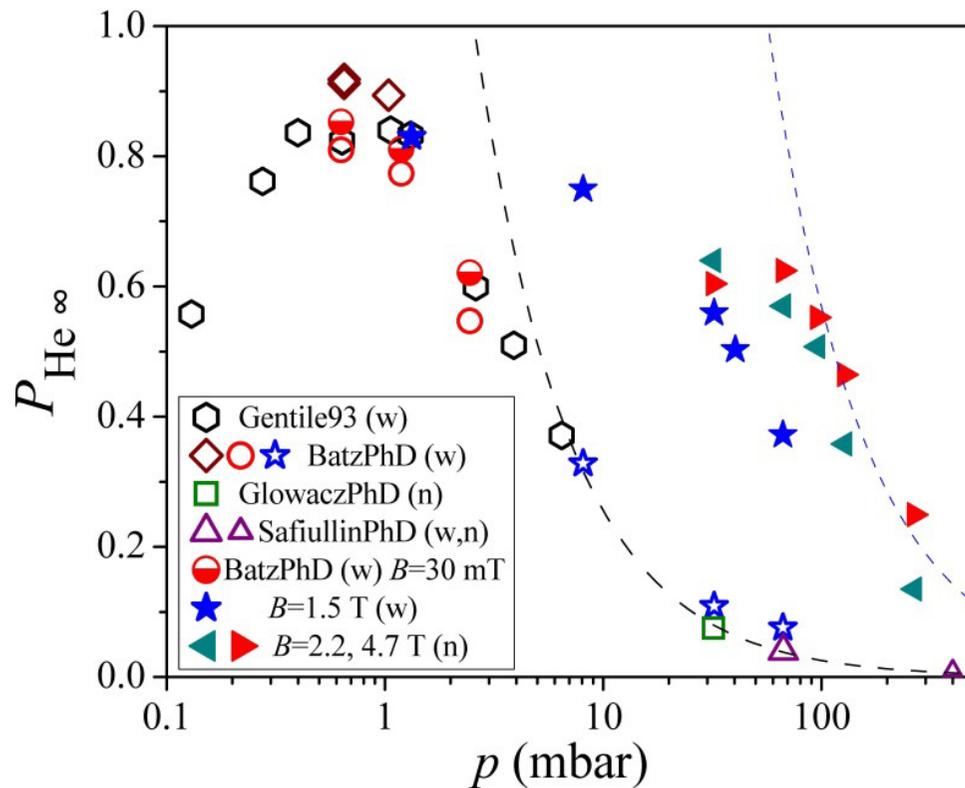
- **Optical Pumping**
- **Metastability exchange**



1 - Polarised ^3He : Applications, polarisation methods

MEOP in optimal conditions is very efficient

- at low B, high P_{He} are achieved (p -dependent)
- at high B, high P_{He} still achieved despite hyperfine decoupling, decrease of P_{He} with p strongly reduced



Decrease with p tentatively attributed to fast relaxation, systematically observed at high OP power.

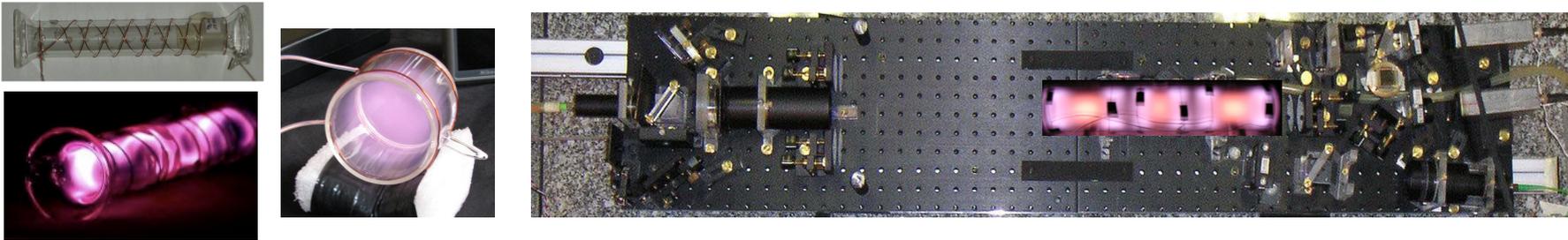
Physical mechanism? Way around?

**PhD thesis of Ali Dia,
under completion**

2 - The **Polarised helium and quantum fluids** group at LKB

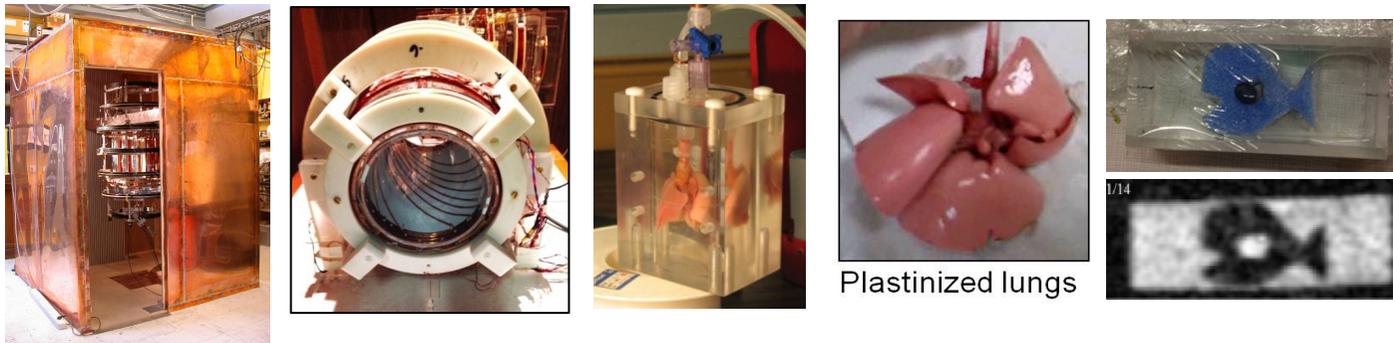
Expertise:

- Laser optical pumping, MEOP: long-standing activity, variety of equipment
see www site <http://www.lkb.upmc.fr/polarisedhelium/polarised-helium-and-quantum-fluids/meop/>



- NMR & MRI in hyperpolarized systems (low or high field, liquid or gas).

see www site <http://www.lkb.upmc.fr/polarisedhelium/polarised-helium-and-quantum-fluids/mri/>



Plastinized lungs

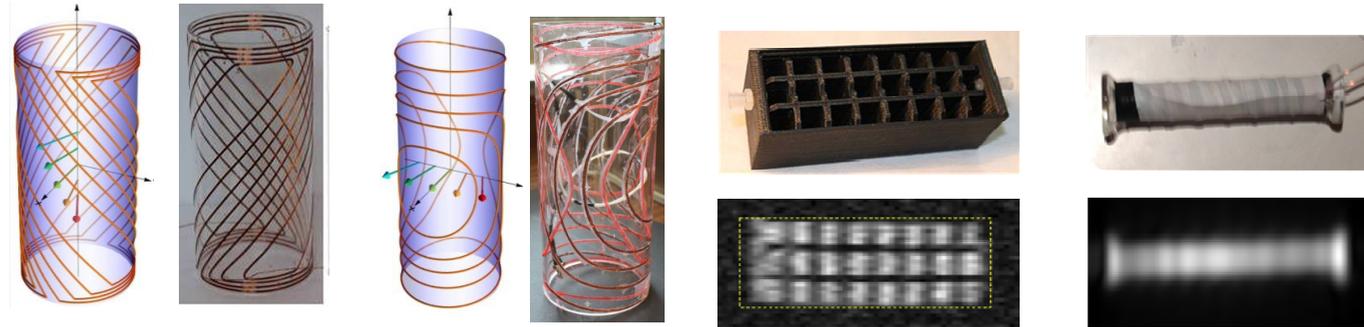
2 - The **Polarised helium and quantum fluids** group at LKB

Running projects:

- **Unconventional NMR/MRI** techniques (with C. Bidinosti, Winnipeg U.)

see www site <http://www.lkb.upmc.fr/polarisedhelium/polarised-helium-and-quantum-fluids/meop/>

Gradient-free
low-B (3-6 mT) MRI
using special rf coils
to avoid usual
low-B artefacts

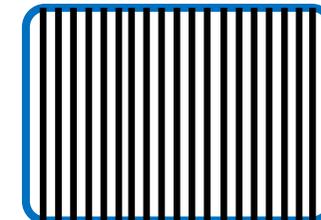
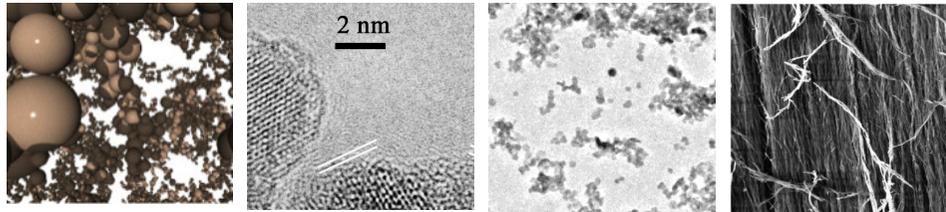


- **MARGIN**, collaborative project (with Kazan Fed. Univ, 2020-2023)

MAgnetic **R**esonance studies of **G**as diffusion **I**n **N**anoporous materials

see www site <http://www.lkb.upmc.fr/polarisedhelium/polarised-helium-and-quantum-fluids/margin-project/>

SiO₂ aerogels,
isotropic
or oriented
nanoporous
samples



Si or SiO₂
plates,
0.1mm gaps

Probe gas diffusion by NMR of ³He and ¹²⁹Xe (*Experimental and theoretical studies*).

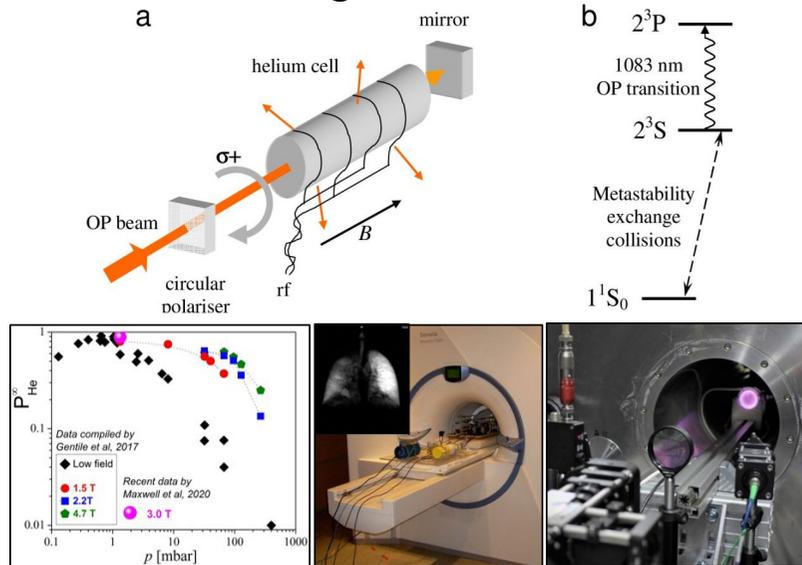
- high and low T (300 K-1.5 K), high and low densities
- wide range of time and distance scales.

2 - The Polarised helium and quantum fluids group at LKB

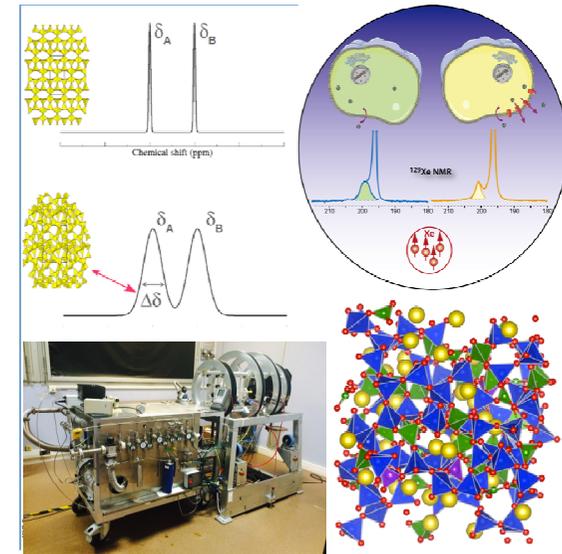
- **HELPING** (2021-2025) High-field Enhancement of nuclear Polarisation In Noble Gases

LKB, Paris

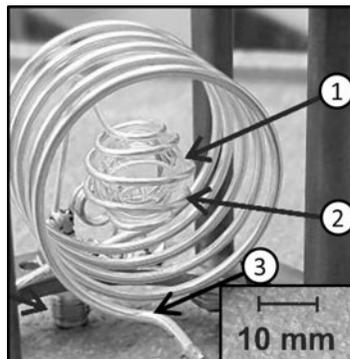
MEOP, High-B studies



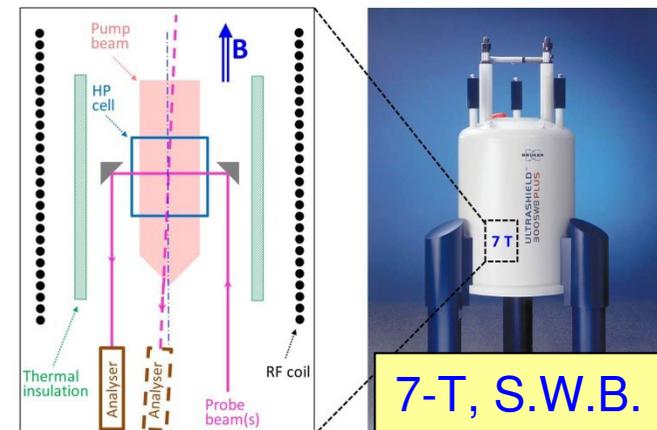
NIMBE / CEA, Saclay
Spin-Exchange OP



PAMP



PhD project



3 - Internship Project and PhD topics - PAMP

Polarization of Atoms in a Magnetized Plasma

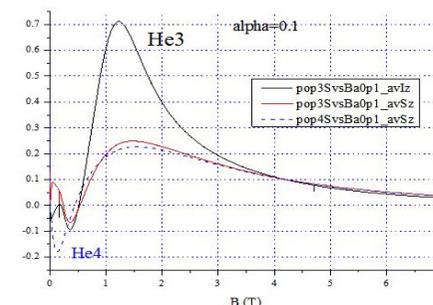
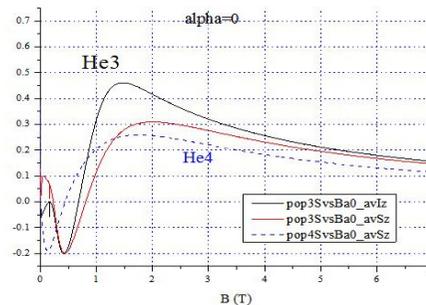
Spontaneous orientation of ^3He nuclear spin (P_{He} up to 10%) was recently observed in strong radiofrequency (rf) gas discharges at high field ($B > 1 \text{ T}$).

Maul et al, *Phys. Rev. A* 98 (2018) 063405 <https://arxiv.org/abs/1806.07624>

We propose an OP-free physical mechanism for PAMP:

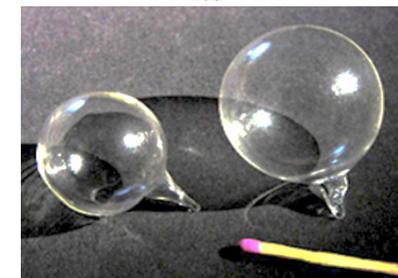
- anisotropic excitation to the 2^3P level by electron - atom collisions (\rightarrow alignment)
- HF coupling + radiative decay (partly) converts alignment to orientation in 2^3S
- ME collisions drives nuclear polarisation to ground state (as in MEOP)

A phenomenological model yields B-dependent predictions, experimental checks are needed



Motivations:

- clarify an unexpected phenomenon (spontaneous apparent symmetry breaking)
- Explore / improve potential performance for applications (e.g. for OP-free high-sensitivity magnetometry)



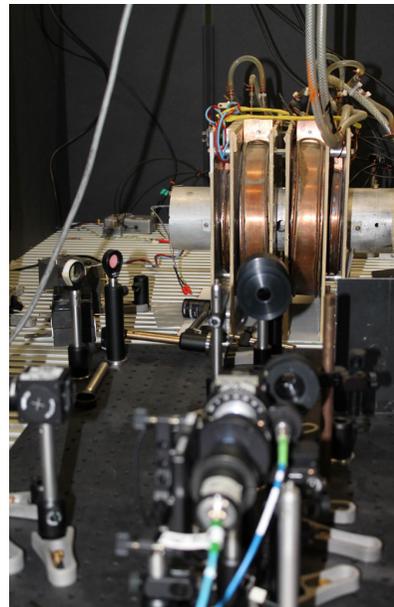
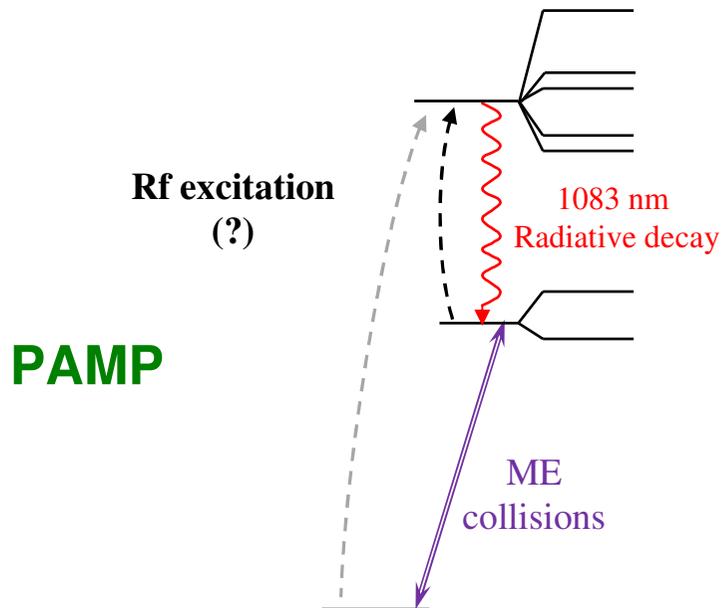
Miniature cells for ^3He magnetometer

3 - Internship Project and PhD topics - **PAMP**

Polarization of Atoms in a Magnetized Plasma

Investigations: Field up to 0,1 T – Pure ^3He or mixtures – Rf frequency and power – ...

- ✓ **Optical spectroscopy**
Selective excitation / detection
- ✓ **Optical polarimetry**
Further selection of probed Zeeman sublevel(s)
- ✓ **No pump laser !**



A. Dia, PhD work on **MEOP**

