# Laser-polarised He-3: a model system, a tool for applications

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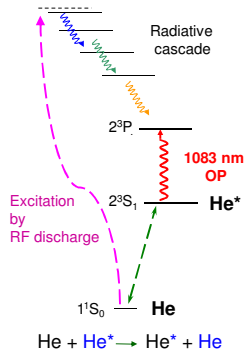
## Polarised $^3$He: methods and applications

**Hyperpolarisation by optical pumping (OP) in a He plasma**

- RF discharge: He ⟶ He* *metastable excited state*
- OP cycles between hyperfine sublevels
  => nuclear spin orientation of He*
- Collisional de-excitation *(fast e⁻ process)*
  => transfer to He *(no loss of nuclear polarisation)*

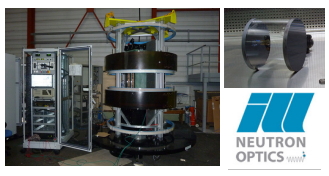


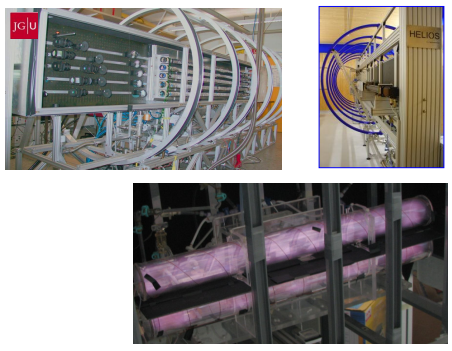

**Standard Metastability Exchange OP**

Room T: 300K $p \approx 1$ mbar $B \approx 0.5$ mT
$M \approx 80\%$ >> $M^{eq} = \mu B/kT$ ($10^{-8}$–$10^{-5}$ for $B$ = 1mT–1T)
Fast pumping: a few tens of seconds
=> **suited for massive gas production**

**Applications of hyperpolarised (HP) $^3$He gas**

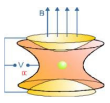
❖ Neutron spin filters (polarisers, analysers)



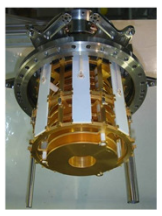



❖ High precision Zeeman magnetometers

$\omega_c = \frac{q}{m} B$



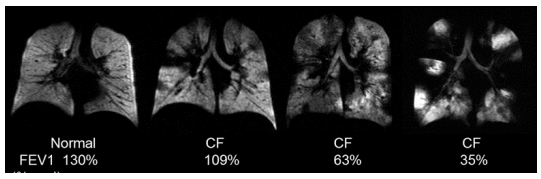
JG|U Joint patent 2013



❖ Nuclear targets…

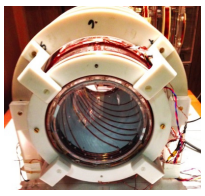
MEOP-based gas polarisers

❖ **MRI of the lung air spaces** (HP gas replaces Boltzmann-polarised H)




From Mentore et al , Acad. Radiol. **12** (2005) 1423.

Faraday cage + MRI

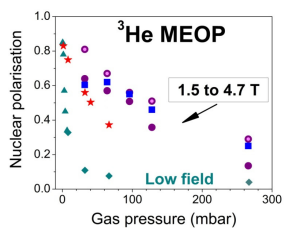


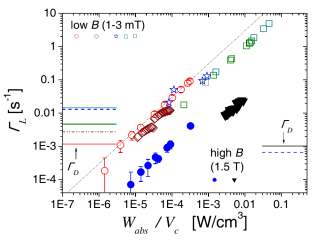
Prototype low-field MR system (¼ –scale)

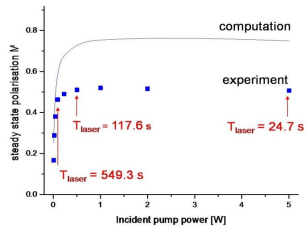
**At LKB : methodological developments, in vitro / in vivo validation**
On-site production of HP gas + MRI at B= 1 to 6 mT + collab. for high-*B* tests

## Collision-induced transfer between $2^3P$ sublevels

A strong enhancement of nuclear angular momentum loss rate occurs during OP



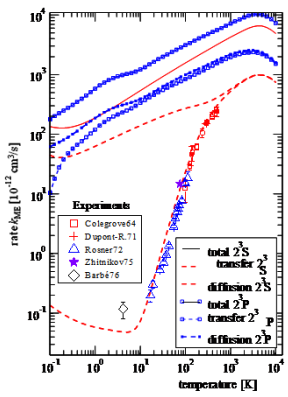



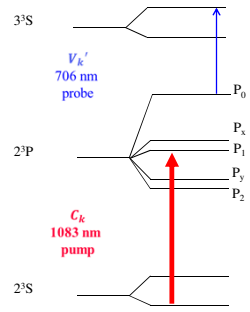

$2^3S$-$2^3P$ is a closed optical transition.
M.E. does not modify orientation

**Need to identify / circumvent the underlying process.**

Excitation transfer between $2^3P$ and ground state atoms : large (computed ) cross section !?

Vrinceanu et al, 2010




**Strategy:** Population monitoring in the $2^3P$ Zeeman sublevels.

**Internship project:** laser resonance spectroscopy, absorption and line shape measurements, optical polarimetry in weak rf gas discharges, use of visible and infrared solid state lasers.

**PhD topics:**

❖ **Develop an improved MEOP model for numerical computations.**

❖ **Extend high-B MEOP to cryogenic temperatures**

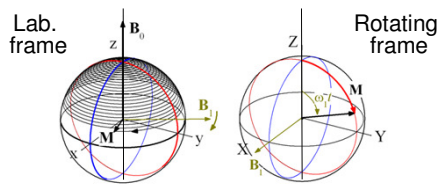
A challenging first step towards high resolution magnetometry at elevated B & low T

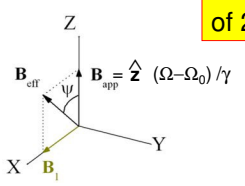
*Very large bore 7 T magnet under implementation at CEA Saclay – WideNMR project (2016-2019).*


## Exotic travel on the Bloch sphere in NMR

**Conventional NMR:** Rotating wave approximation (RWA)
=> Evolution driven by the resonant circular component, $B_1^+$.

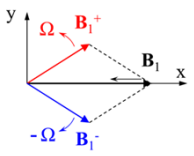
Similar to time-evolution of 2-level quantum systems




Resonant $B_1$ => Flip angle $\alpha = \omega_1 t_{RF}$ Near resonance: $\mathbf{B}_{eff} = \mathbf{B}_1 + \mathbf{B}_{app}$

RWA is not valid **at low $B_0$** for strong $B_1$ (short RF pulses)!



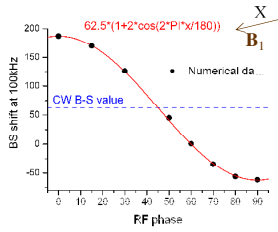
**CW NMR:** well-known (upwards) shift of the resonance frequency

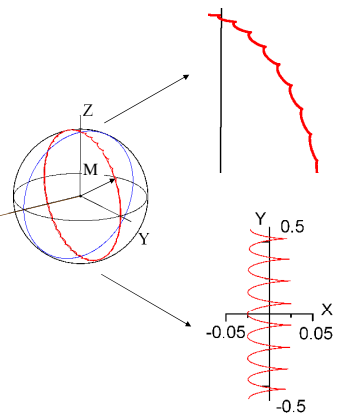
$\delta\Omega / \Omega_0 = (\Omega_1/2\Omega_0)^2 = (1/4N_\pi)^2$

$N_\pi$: number of RF periods in a π pulse

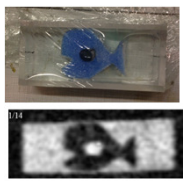
**Need to control pulse errors for all flip angles**

Phase-dependent shifts expected & observed.
Largest shifts (CW×3) for φ=0.



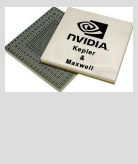
**Internship project:** hands-on NMR or MRI experiments, measurements on polarised gas or water samples, advanced data analysis based on lattice simulations.



**PhD topics:** **Artefacts and limitations in gradient-free imaging**
Bloch Siegert effects - RF gradients

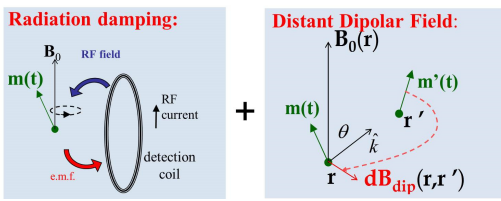
**Impact of restricted diffusion on image quality**
computer lattice simulations, in vitro experiments.

**Comparative in-vivo studies**
lung MRI on small animals at low B and high B



## Taming non-linear NMR with "magic" pulses

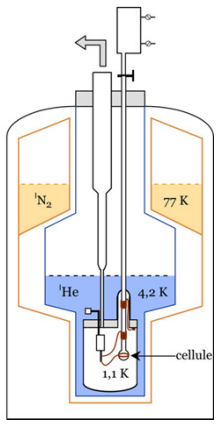
**Nonlinear NMR in strongly magnetised liquids**

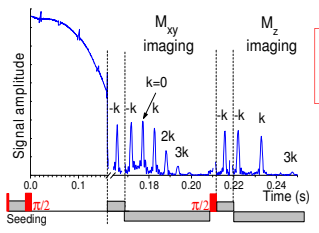



**High density** and nuclear polarisation → Nonlinear terms in the Bloch equations.
Nuclear precession affected by
- **distant dipolar field (DDF)**
- **radiation damping (RD).**

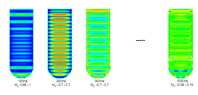
**Low temperature experiments with hyperpolarised $^3$He-$^4$He solutions**

✓ Stochastic maser onset with interplay of RD and DDF
✓ Dynamic precession instabilities




Evidence of parametric amplification of the imprinted pattern (seed), and spatial harmonic generation.



➢ **Remaining challenge:** evaluate and control initial condition ("seed") for free precession following simple or composite RF pulses
Travel on Bloch sphere affected by DDF: immune "magic" pulses?

✓ **New tool:** massively parallel lattice simulations


**Internship project:** make a comprehensive analysis of available data, perform new series of numerical simulations to optimally exploit this material.

**PhD topics:** **will crucially depend on internship findings.**
**→ New generation of experiments?**