# Research project (Master level)

## Proposition de stage Master - *Novembre 2016*


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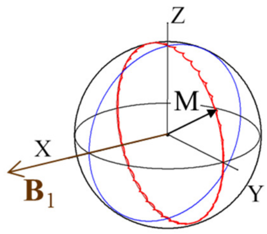
## Titre / *title*: Exotic travel on the Bloch sphere in NMR

**Context -** ***Conventional NMR and MRI*** involve ***a dense medium*** with ***equilibrium polarisation*** in ***high magnetic field***, B (e.g., protons from hydrogen atoms in water or tissues, in B ≥ 1.5T, for clinical MRI). ***With optical pumping techniques*** high out-of-equilibrium nuclear magnetisation (hence, good Signal/Noise ratio) is obtained in $^3$He or $^{129}$Xe and ***gas NMR / MRI*** can be performed ***at arbitrary field strength***, in spite of the low sample density. For lung imaging, hyperpolarised (HP) gas is mixed with air and inhaled just before image acquisition. Low field operation advantageously results in fewer artefacts and longer MR signals, thanks to the weaker field distortions introduced by the bulk magnetic susceptibility of blood and lung tissues.

**Our group at LKB performs methodological developments and in vitro validation of MRI in low B** (1 to 6 mT), with on-site production of HP gas, and resorts to collaborations for high-B and/or in vivo tests. Recent work has been focused on **tests of a "gradient-free" MRI scheme**, TRASE (spatial encoding of the NMR signal is achieved by the RF excitation field, rather than by static field gradients), and on investigation of NMR **response to very short RF pulses** (with duration reduced to a few RF periods).

**Internship project -** In conventional NMR, time evolution can be legitimately described in the rotating wave approximation (RWA). Driven by the resonant circular component, $B_1^+$, of the applied linear oscillating field, the magnetization vector nutates in the Larmor frame around an effective static field which results from the combination of $B_1^+$ and of the residual longitudinal component, $B'_z = \gamma(\Omega\text{-}\Omega_0)$, as would be the case for a 2-level quantum system. RWA obviously breaks down at low B for strong $B_1$, which leads to the well-known Bloch-Siegert (upwards) frequency shift for cw excitation.




Our group uses pulsed NMR and needs good control of pulse errors for all flip angles, both for room-T MRI and low-T studies of $^3$He solutions. We expect and observe unconventional responses to short rf pulses (such as phase-dependent variations of the sign and amplitude of the frequency shift, for instance).

The student will help investigating skewed trajectories on the Bloch sphere and solving specific experimental problems. The objective is to develop improved methodological tools which may also found use in quantum computing or coherent control of Qbits.

*Work will include hands-on NMR or MRI experiments on optically polarised gas and thermally polarised water samples, as well as careful data analysis based on numerical lattice simulations of spin dynamics.*

**PhD work -** An important objective of our group is the development of new methods with improved performance for low field MRI, and a precise evaluation of their pros and cons. Application to lung imaging currently provides the driving momentum to this work. The evaluation of the potential benefits (improved time or spatial resolution, contrast, sensitivity, specificity, etc.) and practical limitations of low-B MRI will be based on quantitative measurements and comparison with more standard high-field results. One challenging issue in lung MRI with gases lies in the impact of restricted diffusion inside the complex multi-scale airways structure on image quality and contrast.

*This internship project is a good introduction to PhD work and will set one of its cornerstones.*

**Read more**: http://www.lkb.science/polarisedhelium/polarised-helium-and-quantum-fluids/mri/
http://www.lkb.science/polarisedhelium/openings-mri/