

New Insights on Precession Instabilities in Highly Polarized Liquids

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Hyperpolarisation (HP) techniques contribute not only to increase NMR sensitivity but, also, to enhance the effects of radiation damping (RD) and long-range magnetic interactions (the distant dipolar field, DDF). This leads to ill-controlled nonlinear dynamics and unusual behaviours that may be due only to DDF (precession instability, spectral clustering, multiple spin echoes: MSEs) or to both RD and DDF (bizarre signals and cross-peaks, spatial-temporal chaos, multiple maser emissions).¹

We pursue in-depth investigations of nonlinear NMR dynamics with dedicated experimental and numerical tools: low field (3 mT) NMR and MRI in laser-polarised liquid ³He-⁴He mixtures at low temperature (1 K), using an active feedback scheme to control RD; numerical simulations for arbitrary sample shapes, by time integration of nonlinear Bloch equations (which may include DDF, RD, diffusion, and applied gradients) ruling the evolution of magnetic moments on a cubic 3D lattice (up to 10⁶ moments and 10⁷ sites available per unit cell).

We report a detailed study of precession instability without RD. MRI-based techniques have been used to induce and probe the evolution of periodic distributions of magnetisation.² Numerical simulations provide new insight on the observed parametric amplification of the imprinted pattern and the generation of spatial harmonics. In particular, we are now able to quantitatively account for the growth rates associated with the precession instabilities. These rates increase linearly with bulk magnetisation, M_0 , and strongly depend on the spatial wave vector, k , of the seed pattern (Fig.1). The influence of sample shape (data not shown) is significant, as noticed in prior work on MSEs.³

Good understanding of precession instability provides the corner stone for further investigation of nonlinear dynamics under the joint influence of DDF and RD, relevant both for NMR with HP techniques and spectroscopy in very high field.

[1] H. Desvaux, Prog. Nucl. Magn. Reson. Spectrosc. 70, 50 (2013).

[2] V.V. Kuzmin et al, Euromar 2013

[3] S. Morgan et al, Eur. Phys. J. D. 67 (2013) 29.

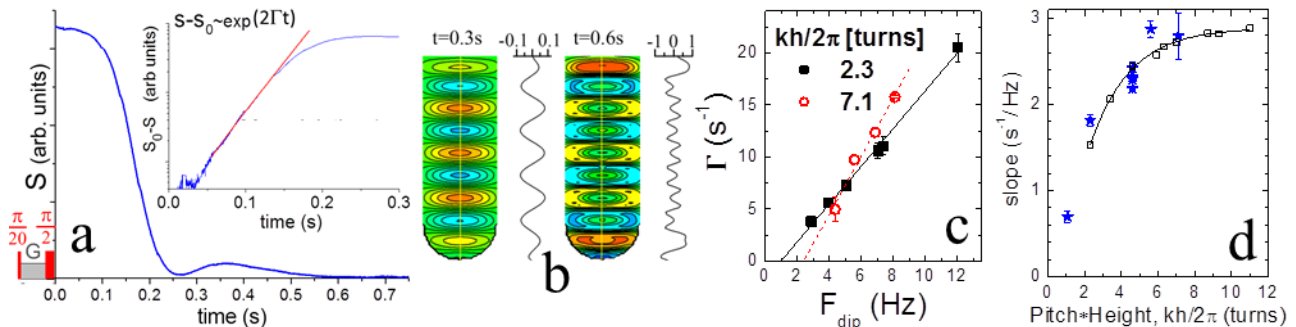


Fig. 1 - a: Experimental FID signal, S , following seed preparation (9° flip and B_0 -gradient pulse, yielding modulation with wave vector $k/2\pi = 5 \text{ cm}^{-1}$) and 90° flip in dilute HP liquid He mixture (4-mm inner diam. tube; fixed sample height, $h=10 \text{ mm}$); inset: semi-log plot of signal departure from initial value, S_0 , yielding the growth rate, G . b: Numerical data (2D map and 1D profile along tube axis) illustrate seed growth and development of harmonics. c) Plots of growth rates versus with dipolar frequency parameter, $F_{\text{dip}} = \mu\omega\gamma M_0/2\pi$. Negative offsets are due to diffusion with damping rates, $-Dk^2$ (depending on ³He concentration). d: Comparison of experimental (blue stars) and numerical slopes, dG/dF_{dip} (open squares; solid line is a guide for the eye).