Title	**MOdelling hyper-Polarization transfer in Solution (MOPS)**

Proponent	Mirco Zerbetto
Research Group	Theoretical Chemistry Group
Contact	web: https://www.chimica.unipd.it/theochem/
	email: mirco.zerbetto@unipd.it
Co-Proponent	Gabriele Stevanato
Research Group	EPR Group
Contact	web: https://www.chimica.unipd.it/eprlab/
	email: gabriele.stevanato@unipd.it

International Secondment	
PI	Daniel Abergel
Institute	Laboratoire des biomolécules, LBM, Département de chimie, Ecole normale supérieure, PSL University, Sorbonne Université, CNRS, 75005
Place, country	Paris, France
# months (min.3)	6

Project description (2 page max):

Introduction - *Signal Amplification By Reversible Exchange* (SABRE) is a promising hyperpolarization technique that enhances NMR signals by transferring spin order from parahydrogen to substrate. Spin order transfer takes place in a transient organometallic complex which binds both parahydrogen and substrate molecules; after dissociation of the SABRE complex, free hyperpolarized substrate molecules are accumulated in solution [D. Barsky et al, Prog. Nucl. Magn. Res. 114–115 (2019) 33–70].

The project is dedicated to an in-silico description of the transfer of hyper-polarization based on 1) the stochastic description of the roto-translational and internal molecular of all the species involved, in organic or aqueous solutions; 2) the coupling of the dynamics to the kinetics of the quantum elementary event of transfer of hyperpolarization; and 3) the dependence upon structural and dynamical properties of the catalyst. All the necessary formal methods will be merged into a comprehensive model: effective Hamiltonian for the spin dynamics + statistical approach to molecular relaxation + stochastic Liouville formalism to couple quantum (spin) and classical degrees of freedom. This will build-up a (possibly) predictive tool aimed at the optimization of the system by guided design of experimental conditions and catalyst structure.

Project goals - We intend to apply in-silico methods capable to i) realistically describe the spin transfer in time adopting a molecularly detailed view of the ensemble parahydrogen + organometallic catalyst + substrate and ii) optimize the efficiency of the organometallic catalyst in carrying on the spin order transfer.

Methods - Several factors would be affecting the (simulated) system:

- transport dynamics: the three-body diffusion of the three components should involve a full description of their roto-translational dynamics;
- molecular structures/dynamics: both the catalyst and the substrate should be described including explicitly shape (internal) coordinates [A. Polimeno et al, J. Chem. Phys. 150 (2019) 184107];
- magnetic interactions: a semi-classical approach could be applied to the “reactive event” (i.e. the spin transfer).

A comprehensive description can be based on a stochastic Liouville formalism [D. J. Schneider, J. H. Freed, Adv. Chem. Phys. 73 (1989) 387-527], with a time evolution operator made of i) a super-Hamiltonian describing the transfer, $\widehat{H}^{\times}(\mathbf{q}_{\mathrm{H}}, \mathbf{q}_{\mathrm{C}}, \mathbf{q}_{\mathrm{S}})$ where the coordinates $\mathbf{q}$ include the positions, orientations and shapes of, respectively, the parahydrogen molecule (H), the catalyst (C), and substrate (S), and ii) a Fokker-Planck operator for the probability density $\hat{\Gamma}$ acting on $\mathbf{q}_{\mathrm{H}}, \mathbf{q}_{\mathrm{C}}, \mathbf{q}_{\mathrm{S}}$.

Numerical approaches should be considerably sophisticate considering the relatively large number of internal coordinates. Possible approaches to be explored will be time-dependent variational principle (TDVP) approaches [J. Haegeman et al, Phys. Rev. B 94 (2016) 165116], and asymptotic approximations.

Work-plan (36 months)

I. Bibliographic research (1-2 months)
II. SLE model definition (2-4 months)
III. A simplified approach to a three-body problem in solution with TDVP methods (6 months)
IV. Description of internal degrees of from in supramolecular systems (4-6 months)
V. Solution of full SLE (8 months)
VI. Exploration and optimization of molecular parameters (8 months)
VII. Thesis writing (2 months)

Additional possible developments – e.g. coarse-grained (semi-explicit) description of medium and systematic exploration of parameters space via ML methods – will be explored during phases IV and V. An international secondment will take place during phases III and IV.