The Ampere Prize 2020 for Young Investigators

The AMPERE prize for young investigators was awarded to Prof. Dr. Thomas Theis at the virtual EUROMAR conference (Bilbao, Spain) on December 8th 2020. The prize was awarded in recognition of his achievements in hyperpolarization and long-lived states.

Dr. Theis established a nuclear spin hyperpolarization technique that enhances NMR and MRI signals on heteronuclei (e.g. ^{15}N, ^{13}C, ^{19}F etc.) by several orders of magnitude.[1–4] His technique, dubbed SABRE-SHEATH (for Signal Amplification By Reversible Exchange in Shield Enables Alignment Transfer to Heteronuclei), is a parahydrogen based hyperpolarization technique that works directly in room temperature solutions to hyperpolarize small molecules including vitamins, drugs and metabolites.[4] SABRE-SHEATH breaks the sensitivity limitations of NMR and MRI, and opens new windows of opportunity for magnetic resonance techniques.

By studying the detailed chemical mechanisms and nuclear spin dynamics controlling hyperpolarization transfer, Dr. Theis was able to maximize hyperpolarization on many substrates and to store hyperpolarization in long-lived quantum states.[5–7] His lab continues to work on parahydrogen and ventures into new hyperpolarization strategies. For example, he now devises optically induced hyperpolarization in room temperature solutions by exploiting optically excited states, spin selective photo-physics and Overhauser dynamic nuclear polarization. His lab explores new applications enabled by his breakthroughs in hyperpolarization chemistry illustrated in Figure 1.

in Fig. 1a show, Dr. Theis' developments of *portable NMR for "chemical analysis on your cell phone"* by combining hyperpolarization technology with highly sensitive Rubidium vapor magnetometers.[8–10] NMR signals are detected from the hyperpolarized molecules with Faraday rotation of polarized light as it traverses the Rubidium vapor. All components, including hyperpolarization unit, spectrometer, optical detector, electric amplification circuits can be miniaturized to obtain well resolved, information rich NMR spectra.

Fig. 1b illustrates the development of *"NMR microscopes"* by exploiting nitrogen-vacancies in diamond as optical quantum sensors of hyperpolarized NMR signals.[11] Here the power of optical microscopy is expanded by the chemical dimension, because we will be able to acquire NMR spectra of every pixel in optical images. Hyperpolarized tracers can be fed to cells on the surfaces quantum sensing chips that are imaged with microscopic resolution to monitor metabolic turnover in cells.

As shown in Fig. 1c, Dr. Theis establishes *"decoherence-free quantum sensors"* by generating large negative nuclear spin polarization in highly resonant RF circuits. This results in a RASER, which in analogy to a LASER, also emits highly coherent waves, except the RASER waves are in the kHz to MHz regime and reports directly on chemical structure through chemical shifts and *J*-couplings.[12,13] With a RASER one can achieve arbitrarily narrow NMR lines to obtain precision measurements of NMR parameters.

Finally, depicted in Fig. 1d is another major thrust in the Theis lab geared towards "affordable molecular imaging" by hyperpolarized MRI. The Theis lab created a cryogen-free MRI system featuring magnetic fields between 5 mT and 3 T. His lab is showing that with hyperpolarized MRI there is no longer a need for magnetic fields of large superconducting magnets for high quality molecular imaging. With these tools, the Theis lab can track the metabolic turnover of individual metabolites directly in animals and patients,[14] setting the stage for affordable MRI.

In summary, Dr. Theis is emerging as a leader in hyperpolarization chemistry and its applications to quantum sensing and molecular imaging. The Theis lab fosters deep knowledge of chemical kinetics and spin evolution to continually innovate spin technologies and molecular imaging modalities.

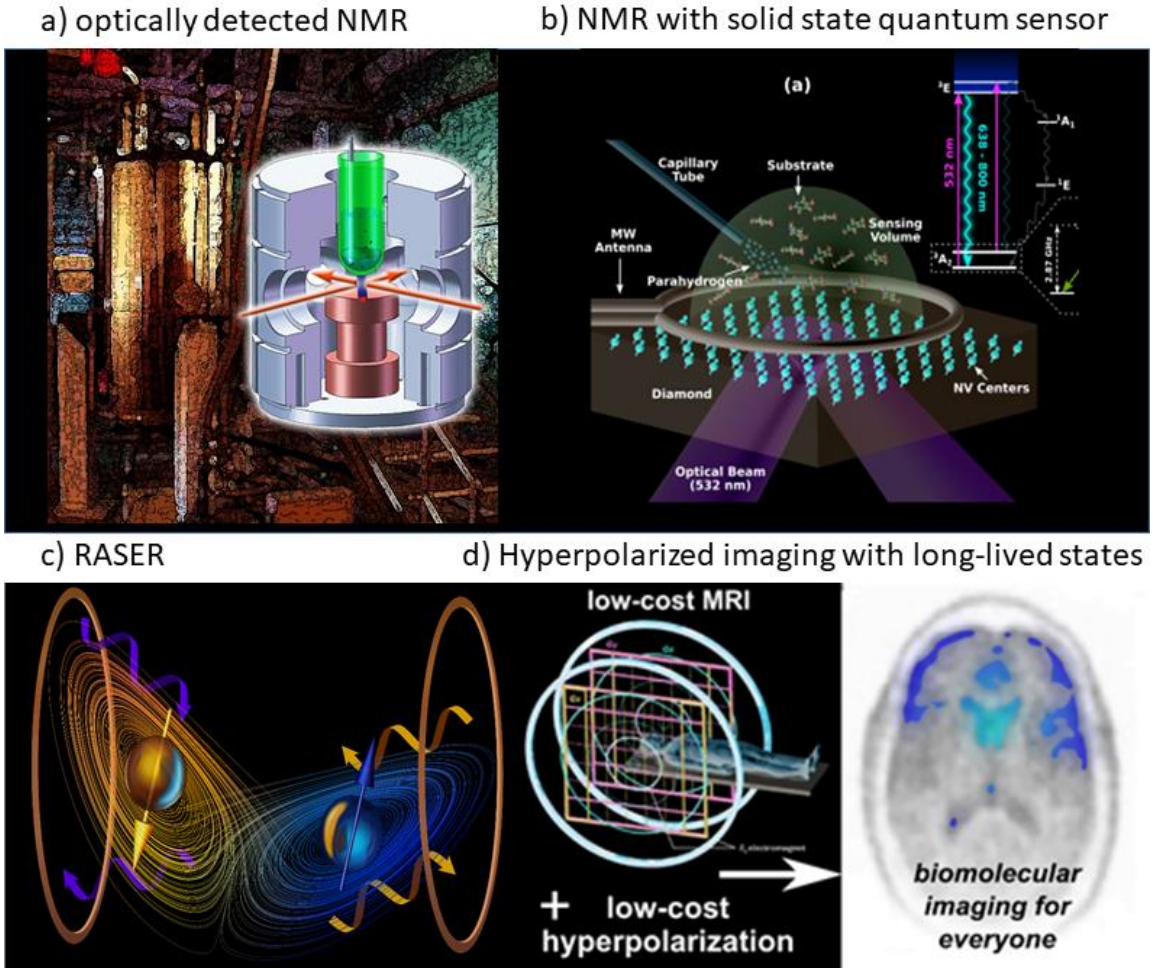

Figure 1. Achievements in the Theis hyperpolarization lab.

a) Rubidium vapor magnetometer for miniaturizable NMR (see refs. 8-10)
b) NV-diamond detected NMR (see ref. 11)
c) Radiofrequency amplification by stimulated emission of radiation (see refs. 11,13)
d) Molecular imaging with long-lived hyperpolarization (see refs. 1-7)

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