without any final conditions whatsoever, we are back to a decoherence approach as most predictive: this approach attempts to describe the emergence of the current state of the Universe through a physical process in which accidents may arise, but do not affect the overall theory.

So will the no-boundary, top-down cosmology really turn the string landscape into a goldmine of physical predictions? Hawking and Hertog's paper is mainly about how to interpret physics from the top-down perspective, with few supporting calculations, so their answer remains uncertain. Clearly, with too much leeway in choosing final conditions (these might include, the authors propose, the number of dimensions in space-time, or the observed features of the standard model of particle physics), physics is in danger of becoming a tautology — a proposition already true by definition. But approached carefully, a top-down viewpoint on cosmology can, at some expense of losing explanatory power, serve well as an interpretational framework to test theories in the string landscape.

Hawking and Hertog's work also represents a welcome attempt to combine pivotal ideas from different approaches to quantum gravity. Such cross-fertilization has rarely happened, but can only improve our overall understanding. That such efforts should continue is indeed, to return to Hamlet, "a consummation devoutly to be wished". ■

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1. Kachru, S., Kallosh, R., Linde, A. & Trivedi, S. P. *Phys. Rev. D* **68,** 046005 (2003).
2. Susskind, L. preprint available at www.arxiv.org/hep-th/0302219 (2003).
3. Hawking, S. W. & Hertog, T. *Phys. Rev. D* **73,** 123527 (2006).
4. Hartle, J. B. & Hawking, S. W. *Phys. Rev. D* **28,** 2960–2975 (1983).
5. Vilenkin, A. *Phys. Rev. D* **30,** 509–511 (1984).
6. Schiller, F. reprinted in *Hist. Theor.* **11,** 321–334 (1972).
7. Griffiths, R. *J. Stat. Phys.* **36,** 219–272 (1984).
8. Omnès, R. *J. Stat. Phys.* **53,** 893–932 (1988).
9. Gell-Mann, M. & Hartle, J. B. *Phys. Rev. D* **47,** 3345–3382 (1993).
10. Joos, E. *et al. Decoherence and the Appearance of a Classical World in Quantum Theory* (Springer, Berlin, 2003).

SPECTROSCOPY

Shifting light with spin

Warren S. Warren

NMR spectroscopy has changed enormously over the years, but signal detection has stayed the same since the technique was invented. The latest thinking literally shines a new light on things.

Sixty years ago, the forefront of speculative physics research included the nascent field of nuclear magnetic resonance (NMR). Physicists placed atomic nuclei in a strong, constant magnetic field and then watched the voltages induced in a coil when the nuclei were perturbed with weak, finely tuned radio waves. At that time, NMR was a prime example of blue-skies research with no conceivable real-world applications. Since then, spectacular developments have established NMR as the foremost spectroscopic method for chemists, and Nobel prizes in physics, chemistry and medicine have been awarded for advances in NMR. Its descendant, magnetic resonance imaging (MRI) has become a mainstream diagnostic tool in medicine, and functional MRI — essentially, watching people think — may revolutionize neuroscience.

As part of this evolution, almost everything has changed in the basic NMR set-up, except for the method of detection; nearly all NMR and MRI experiments still use the same 'nuclear induction' concept that was used 60 years ago to detect a signal. On page 1021 of this issue[1], Savukov *et al*. report a radically different method to detect NMR signals in liquids: watching the small phase-shifts induced in a laser beam by nuclear spins. Bringing the power of modern optics to NMR detection could greatly improve image resolution, and perhaps even sensitivity. This would be a huge step forward, as many applications, for example in the emerging field of molecular imaging, are limited by these issues.

This is not the first attempt to find a different detection method for magnetic resonance. For example, a tiny magnet placed close to a particle experiences a force exerted by the spin of that particle. Several groups have tried to detect this force directly. Signals from single electron spins[2] or from a few thousand nuclear spins[3] have been observed in this way, but the method is not suitable for macroscopic samples.

There have even been other attempts to use optical detection in magnetic resonance. Under certain circumstances, electron spin-flips are coupled to changes in electronic energy levels, so that electronic spins can simply be measured by observing the light absorbed or emitted as the electrons jump between these levels[4,5]. More generally, there have been many attempts to look at variations in the NMR signals of liquids caused by the optical irradiation of those liquids. The largest changes are expected in the frequencies of signals from electronically excited molecules. Such changes are predicted to be sizeable, but the process required to create an excited population of molecules, known as near-resonant excitation, also heats the sample. This heating induces frequency shifts of its own[6] and severely limits the utility of the method.

The technique now reported by Savukov *et al*.[1] is known as nuclear-spin optical rotation (NSOR). This method looks for phase-shifts induced in a laser beam as it passes through a liquid, rather than for frequency shifts of signals in an NMR spectrum. Detecting an optical effect instead of nuclear spins has several advantages. Measurements of NMR frequency shifts require uniform laser irradiation of the sample, but NSOR can work with much smaller, tightly focused laser beams, which in principle permits micrometre-resolution measurements. This would be a vast improvement over existing techniques; obtaining even 100-micrometre resolution in MRI is challenging, for example.

The NSOR method of detecting phase-shifts in a laser beam allows experimental designs that are less sensitive to sample heating compared with previous methods. Even three-dimensional tissue imaging is not out of the question with NSOR, as near-infrared light can penetrate many centimetres into tissue. NSOR is also enhanced by so-called hyperfine effects, which increase with the mass of the nucleus under investigation. This makes the technique particularly suitable for heavy nuclei, which generally give poor spectra in traditional NMR experiments.

The greatest problem for NSOR at the moment is its sensitivity, which is not yet as good as conventional NMR. But optical detectors can be highly efficient, as single photons are much easier to detect than single spins, and Savukov and colleagues[1] suggest several potential improvements to their technique — for example, bouncing light off mirrors to pass it through the sample many times. In addition, modern technology gives us incredible control of the timing, shape and polarization of ultrafast laser pulses. It is easy to see how NSOR, with a combination of tailored light and modulated magnetization, could couple modern optical imaging methods to MRI. If this happens, it will be yet another reminder that speculative physics research can yield great practical dividends. ■

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1. Savukov, I. M., Lee, S.-K. & Romalis, M. V. *Nature* **442,** 1021–1024 (2006).
2. Rugar, D., Budakian, R., Mamin, H. J. & Chui, B. W. *Nature* **430,** 329–332 (2004).
3. Mamin, H. J., Budakian, R., Chui, B. W. & Rugar, D. *Phys. Rev. B* **72,** 024413 (2005).
4. Jelezko, F., Gaebel, T., Popa, I., Gruber, A. & Wrachtrup, J. *Phys. Rev. Lett.* **92,** 076401 (2004).
5. Kohler, J. *et al. Nature* **363,** 242–244 (1993).
6. Warren, W. S., Goswami, D. & Mayr, S. *Mol. Phys.* **93,** 371–375 (1998).