

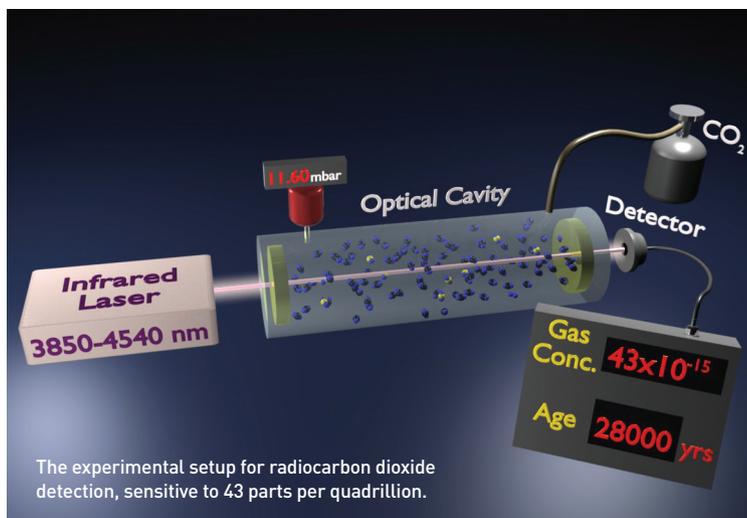
SPECTROSCOPIC APPLICATIONS

All-Optical Radiocarbon Dating

Radiocarbon (^{14}C), the “natural clock” for dating organic matter, is a very elusive atom. Its concentration is about one part per trillion. For the past 30 years, accelerator mass spectrometry (AMS) has been adopted as the standard method for dating organic samples via radiocarbon. AMS requires a smaller carbon mass and shorter measurement times than the old standard method of liquid scintillation counting. However, AMS requires huge, expensive and high-maintenance experimental facilities.

We have developed a laser spectroscopy technique that is sensitive enough to detect the radiocarbon dioxide molecules at very low concentrations with an all-optical setup that is orders of magnitude more compact and less expensive than AMS.¹ The new approach, named SCAR (saturated-absorption cavity ring-down), makes use of molecular absorption saturation to enhance resolution and sensitivity with respect to conventional cavity ring-down spectroscopy.² By combining SCAR with a frequency-comb-linked CW coherent source, which delivers tunable radiation (around 4.5- μm wavelength) by difference-frequency generation (DFG), we could set an unprecedented limit in trace gas detection, accessing the part-per-quadrillion (10^{-15}) concentration range.³ SCAR-based results are currently one order of magnitude shy of challenging AMS, but there is still room for improvement. Moreover, SCAR has a wider dynamic range than AMS—encompassing more than five orders of magnitude in measurable concentration values.

A feasibility study for radiocarbon dating by infrared laser spectroscopy was published over 30 years ago.⁴ We recently succeeded in measuring the spectral area of the selected target absorption line of the $^{14}\text{C}^{16}\text{O}_2$ isotopic species, thus retrieving the absolute radiocarbon dioxide concentration. We accomplished



this by exploiting the unique features of our experimental apparatus and relying on strong molecular absorption in the mid-infrared.

The SCAR technique starts with an optical cavity filled with CO_2 , which is illuminated with an intense CW laser tuned to excite a target molecular transition of $^{14}\text{C}^{16}\text{O}_2$. When the laser is turned off, photons stored in the cavity decay due to $^{14}\text{C}^{16}\text{O}_2$ absorption and mirror leakage. Because light intensity saturates the ability of the $^{14}\text{C}^{16}\text{O}_2$ to absorb it, the initial instants of decay are affected by losses from the mirrors only. Once we subtract that background, we can determine the absolute quantity of $^{14}\text{C}^{16}\text{O}_2$ from the linear molecular absorption encoded in the decay tail.

Our results pave the way to a brand-new all-optical dating technique, moving from detection of high-energy (MeV) accelerated ions to more comfortable detection of low-energy (0.25 eV) absorbed photons. This technique can be used to detect extremely rare molecules with myriad of applications in many fields. **OPN**

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References

1. I. Galli et al. *Phys. Rev. Lett.* **107**, 270802 (2011).
2. G. Giusfredi et al. *Phys. Rev. Lett.* **104**, 110801 (2010).
3. I. Galli et al. *Opt. Lett.* **35**, 3616 (2010).
4. D. Labrie and J. Reid. *Appl. Phys. A* **24**, 381 (1981).