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## First laser spectroscopy of a rovibrational transition in the molecular hydrogen ion $\text{H}_2^+$

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The molecular hydrogen ion  $\text{H}_2^+$  is the simplest molecule. This iconic system has been the subject of innumerable theoretical studies, from the earliest days of quantum mechanics [1] until today, culminating in highly precise predictions of its level energies [2]. Comparisons of these predictions and measured vibrational transition frequencies would offer excellent opportunities in fundamental physics that go beyond the results achieved with the related molecule [3, 4]: a direct determination of the proton-electron mass ratio and the proton's charge radius. Furthermore, achieving precision spectroscopy of  $\text{H}_2^+$  is an essential prerequisite for a future CPT test that compares  $\text{H}_2^+$  with its antimatter counterpart [5, 6].

In this work we report the first vibrational laser spectroscopy of  $\text{H}_2^+$ , between low-lying rovibrational levels of para- $\text{H}_2^+$  [7]. We employed sympathetically laser-cooled and trapped  $\text{H}_2^+$  ensembles. A first-overtone electric-quadrupole (E2) transition [8, 9] was driven by a unique  $10^{-13}$ -level optical frequency metrology system reliably delivering Watt-level laser power at  $2.4\mu\text{m}$ . Both hyperfine components were measured. We determined the spin-averaged rovibrational transition frequency with  $3 \times 10^{-8}$  fractional uncertainty, finding agreement with the predicted value. By using  $\text{HD}^+$  as a test molecule, we also show that E2 spectroscopy is possible with  $1 \times 10^{-12}$  uncertainty. This demonstrates that E2 transitions are suitable for precision spectroscopy of molecular ions and that determining  $m_p/m_e$  spectroscopically with accuracy competitive with mass spectroscopy is a realistic prospect.

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