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When QCLs meet cold molecules

What time is it? Everyone uses a watch but scientists at the Comomet ⁽¹⁾ consortium use a different atomic clock to measure time and are even considering building molecular clocks to define new frequency standards in metrology. A French member of this consortium, the Laboratoire de physique des Lasers (LPL) ⁽²⁾, studies the stability of fundamental physics constants which might play a role in such a new standard. In particular a team constituted by Raphaël Hahn, Benoît Darquié and Mathieu Manceau and others study the proton-to-electron mass ratio variability over time and distance. They probe this ratio with spectroscopy techniques on methanol molecules located in their lab and compare to measurements in galaxies far away from us in time and distance. To this aim, the lab stabilizes the emission frequency of the laser down to an outstanding 10^{-14} level (this means that a quantum cascade laser emitting light at $10\mu\text{m}$ wavelength - which is 30 THz of frequency, ie $3 \cdot 10^{13}$ Hz - will have its frequency stabilized to sub-Hz level). The lab manages this world record QCL stabilization by various means including phase-lock-loop techniques, special current drivers built in-house and locking to a frequency comb calibrated to some of the best atomic clocks in the world. This outstanding frequency stabilization of QCLs is probably unique and the best-in-class today in the world.

The lab also precisely controls the frequency of these quantum cascade lasers to study cold molecules with chiral properties, ie enantiomers. In chemistry, an enantiomer is one of a pair of molecular entities which are mirror images of each other and non-superposable ⁽³⁾, just like the right and left hands. In theory, the difference of energy between two enantiomers is very small and the lab tries to measure this tiny difference with QCL lasers. Among these chiral molecules, the lab is interested in studying heavy, and thus relatively complex, species. The heavier the molecule, the less energy is required to excite such molecule and therefore, the lab has special interest in QCL lasers with lower frequencies such as the 17 microns wavelengths ⁽⁴⁾ QCLs from mirSense, all the more since it happens that complex molecules are better measured with light above $10\mu\text{m}$ wavelength.

In the future they would therefore like to study cold chiral molecule transitions with mid-infrared (MIR) QCLs with wavelength $>15\mu\text{m}$

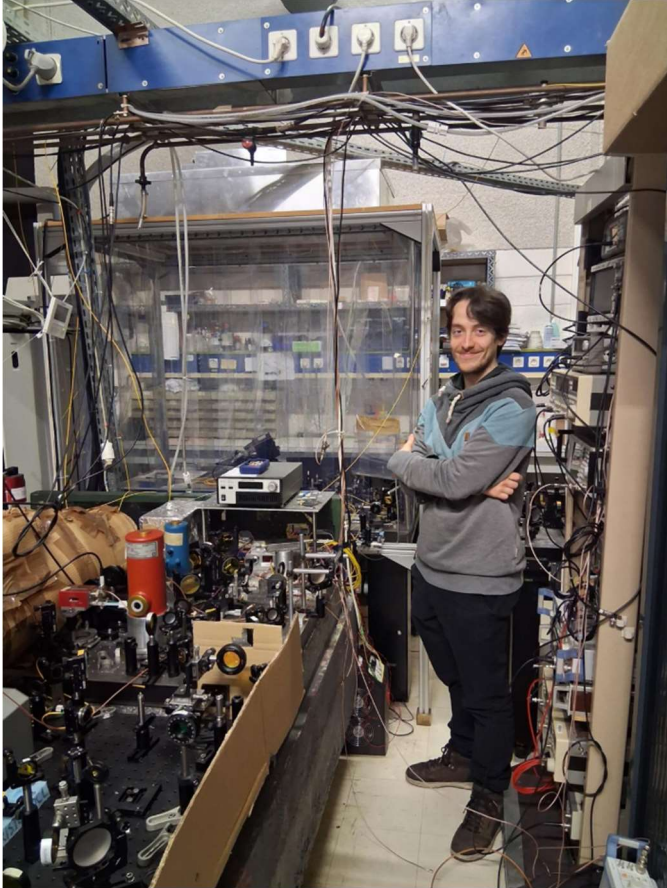
⁽¹⁾ <https://comomet.lens.unifi.it/index.php?n=Main.HomePage>

⁽²⁾ <https://www.lpl.univ-paris13.fr/en/>

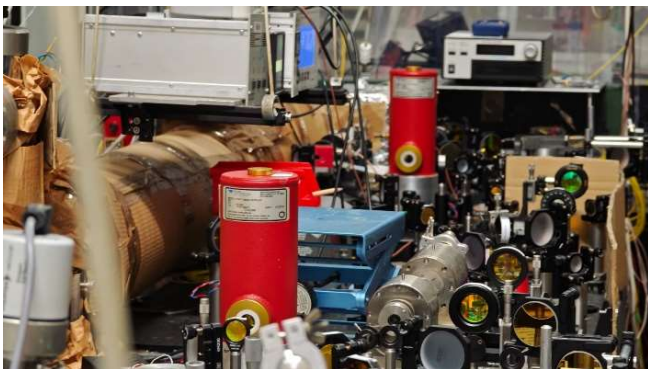
⁽³⁾ <https://en.wikipedia.org/wiki/Enantiomer>

⁽⁴⁾ <https://arxiv.org/abs/2310.16460>. "Demonstration and frequency noise characterization of a 17 μm quantum cascade laser"

<https://doi.org/10.1002/lpor.202500879> M Manceau, TE Wall, H Philip, A N Baranov, O Lopez, MR Tarbutt, R Teissier, B Darquié, *Demonstration and frequency noise characterization of a 17 μm quantum cascade laser*, Laser Photonics Rev, e00879 (2025)



Raphaël HAHN, a scientist working in the ‘Laboratoire de Physique des Lasers’, standing next to what is probably the QCL with the most stable frequency (down to 10^{-14})



Picture of an optical bench in the ‘Laboratoire de Physique des Lasers’