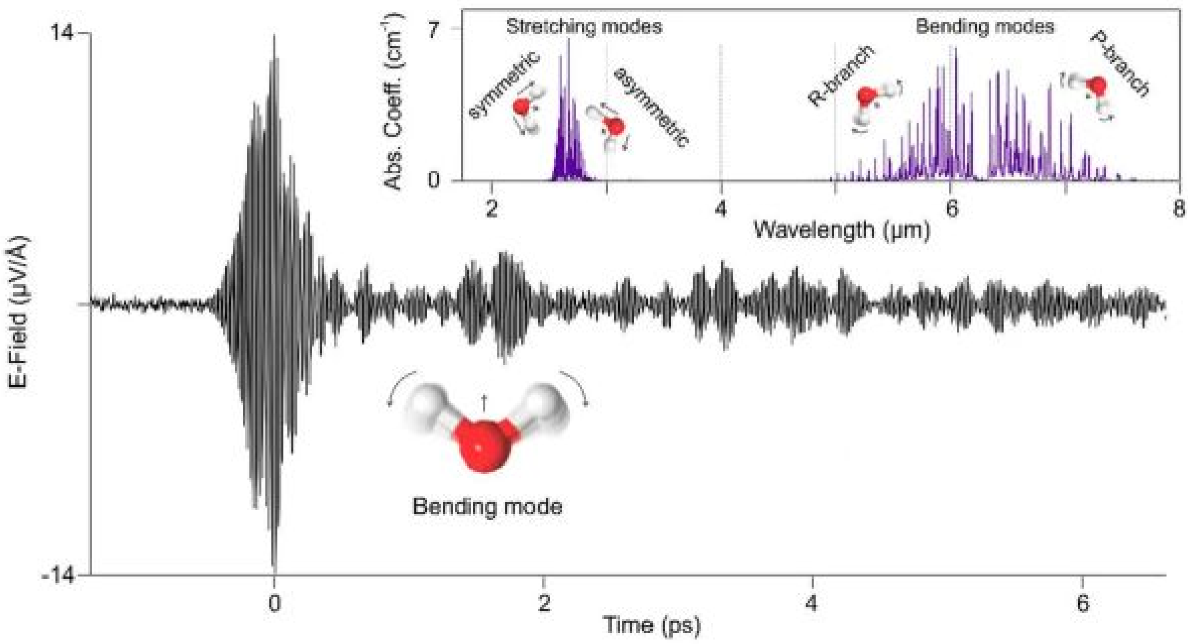

ICFO researchers predict how mid-infrared light propagates in atmosphere

ICFO researchers have developed a numerical method, validated by experimental results, which accurately predicts that the shape of mid-infrared light pulses changes after travelling in the air, especially under high levels of humidity.

August 16, 2024

How does a light pulse propagate through the atmosphere? Although this question might seem naive, answering it requires accounting for multiple interactions with different atmospheric molecules, variable conditions across space and time, and several atmospheric parameters such as temperature, humidity and pressure. This complex interplay of factors makes it extremely difficult to find a complete solution to the question, something that has not been fully accomplished yet.

However, the scientific community is deeply interested in this problem, as the ability to predict atmospheric light propagation is key to numerous applications. These include

remotely sensing atmospheric constituents for climate or weather prediction, monitoring pollutants and other harmful substances, detecting remote light sources like guide stars, and delivering energy on targets.
ICFO researchers, **Christian Hensel**, **Dr. Lenard Vamos**, **Igor Tyulnev**, **Dr. Ugaitz Elu**, led by **ICREA Prof. Jens Biegert**, have now made significant progress toward addressing this challenge. Focusing on mid-infrared light, the team developed a model that accurately predicts how the intensity and profile of these pulses change as they travel through the air. Experiments conducted by the researchers strongly corroborated the model's predictions. Their findings, published in APL Photonics, reveal how the **pulse shape broadens during atmospheric propagation, with water vapor identified as the main contributor** to this effect.

Modelling the atmosphere: an intricate challenge
ï¿½We measured the initial electric field of an optical pulse at its origin and then applied t
e model to predict its propagation. We then compared the prediction with another fie
d resolved measurement taken after propagationï¿½, says ICREA Prof. Jens Biegert, explai
ing in simple terms the procedure followed in the study. But the truth is that it was much a
ore sophisticated process. The modelling, for instance, involved using a high accuracy data
ase of atmospheric constituents at various temperatures and humidity levels. These constitu
nts absorb and disperse light at thousands of different frequencies, and these frequen
ies change transiently during the pulse itself. ï¿½Understanding which approximations co
ld be made in the model to reduce complexity and increase speed, while still including tho
sands of absorption lines, was very demandingï¿½, admits Prof.
iegert. Moreover, air is not just oxygen and nitrogen; it contains large amounts of water as
ell. In particular, researchers had to account for the so-called top-hat water molecule
n their simulations. This molecule has a significantly complex absorption spectrum, tu
ning the modelling process into an even more ardu

The pulse spreads out in the presence of water vapor
In the end, the team succeeded in incorporating all these parameters into their model. According to it, the process begins with very short and precise light pulses. As the pulses travel, they interact with atmospheric molecules, which absorb and re-emit light in random directions in a much longer decay time compared to the laser pulse. Consequently, the pulse duration increases and a long complex tail from the interference among the re-emitted light appears, degrading the initial well-defined shape. The model also showed that as humidity increases, reshaping becomes even more pronounced due to additional absorption and dispersion effects caused by excess water vapor.
Then the researchers conducted sensitive experiments in the time-domain, reproducing the predicted effects which excellent agreement, thus validating the model. ï¿½Our method
s general and easy to apply for any gas compositions and pulse shapesï¿½, shares Dr. Le

ard Vamos. And he adds: ï¿½This ability to predict atmospheric propagation could nhance many technologies, where estimating pulse's features is essential for efficient desi ns. It could also be critical for many spectroscopic techniques, where pulse reshaping educes temporal resolution and provides insight into the interaction process its

Reference:
Christian Hensel, Lenard Vamos, Igor Tyulnev, Ugaitz Elu, Jens Biegert; Propagation of broadband mid-infrared optical pulses in atmosphere. APL Photonics 1 August 2024; 9 (8): 080801.
DOI: https://doi.org/10.1063/5.0218225

Acknowledgements:
The authors acknowledge financial support from the European Research Council via ERC Advanced Grant ?TRANSFORMER' (788218) and ERC Proof of Concept Grant ?mini-X' (840010), the European Union's Horizon 2020 for ?PETACom' (829153), FET-OPEN ?OPTOlogic' (899794), PATHFINDER-OPEN ?TwistedNano' (101046424), Laserlab-Europe (871124), Marie Sk?odowska-Curie grant no. 860553 (?Smart-X'), MINECO MINECO for ?AttoQM' PID2020-112664GB-100, AGAUR for SGR-2021-01449, ?Severo Ochoa' (CEX2019-000910-S), Fundacio Cellex Barcelona, CERCA Programme/Generalitat de Catalunya and the Alexander von Humboldt Foundation for the Friedrich Wilhelm Bessel Prize.