Intense laser beam enhancement and destruction by quantum wakes in air

Tiny quantum mechanical lenses moving at the speed of light are shown to enhance or destroy the propagation of intense ionizing laser pulses in the atmosphere.

Summary: Scientists at the University of Maryland have discovered that tiny quantum mechanical lenses composed of nitrogen and oxygen molecules and moving at the speed of light can steer, enhance, or destroy high power laser filaments in air [1]. These laser filaments may be very useful for directed energy applications, remote detection of chemicals, and triggering and guiding of high voltage electrical discharges such as lightening.

Background: When a very short, typically less than 100 femtosecond, high energy laser pulse travels through the atmosphere, it can collapse into a very narrow beam and form a thin filament of ionized air that can be over 100 meters long. This happens when the pulse is bright enough to focus in air on its own without the aid of a lens. This is called “self-focusing”. When the laser pulse reaches a strong enough focus, it can rip electrons off the air molecules, nitrogen and oxygen, leaving a long track of ionized air, called a plasma. The plasma acts like a negative lens, defocusing the laser pulse. The air self-focusing and plasma defocusing dynamically balance each other to cause the laser pulse to remain as a tight, narrow beam for many meters. As long as the laser pulse stays focused, it leaves a ~100 micron diameter region of plasma--a filament—behind it.

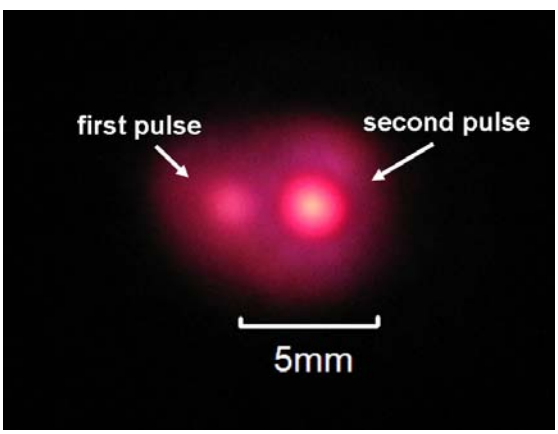

Figure 1. Image of two filamenting laser pulses hitting a screen.

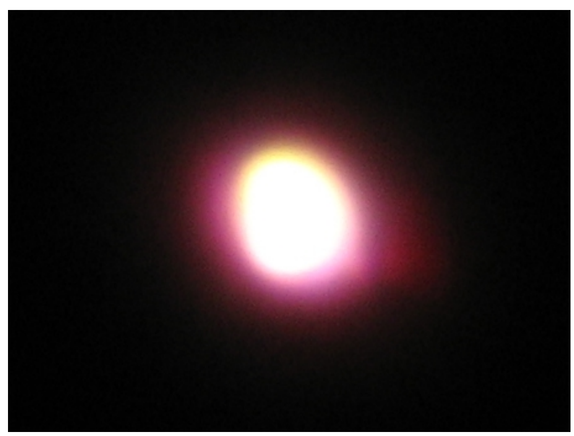

Figure 2. The same two filaments separated in time so that the second filament is steered, trapped and guided by the quantum molecular lens of the first .

The filament cannot extend forever, because the laser pulse loses energy as it continues to ionize air molecules, and it gradually defocuses. However, a short intense laser pulse can also leave nitrogen and oxygen molecules spinning in its wake—like the water wake of a boat-- as it propagates through the air. Maryland scientists found that the molecular spinning remains undisturbed even inside the hot, dense plasma filament, and that after a delay of eight picoseconds the molecules spontaneously line up. Since aligned molecules have a higher index of refraction than normal air, they act in concert like a tiny "molecular lens" traveling at the speed of light, eight picoseconds behind the laser pulse. This lens is in fact a quantum mechanical effect that arises because the molecules do not spin over a continuous range of speeds as one might imagine them to do classically; they spin only at certain allowed 'quantized' speeds governed by quantum mechanics. The sum effect of these quantized rotational speeds is extremely short (50 femtosecond) bursts of alignment (acting as a focusing lens) and anti-alignment (acting as a defocusing lens) that follow the laser pulse at special characteristic times. The 8 picosecond delay is one such special time for nitrogen and oxygen alignment.

The Maryland scientists hoped that they could increase the length of an initial filament if they sent a second strongly filamenting laser pulse 8 picoseconds behind it. They reasoned that the "molecular lens" following the first pulse would help the second laser pulse stay focused and increase the length of the plasma filament. The effect turned out to be even more dramatic than expected. The focusing effect of the aligned molecules was so strong that even when the two pulses were launched in slightly different directions, the second pulse filament was sucked sideways into the quantum wake of the first pulse filament! And when the second pulse delay was changed by only 50 femtoseconds to experience anti-alignment, its filament was destroyed.

The above pictures are beam images of two filamenting laser pulses propagating 6 meters across a room and hitting a screen. In Figure 1, the spots on the screen are separated because the filaments were launched in slightly different directions and with a non-special delay. When the second pulse is delayed from the first pulse by 8 ps to encounter the quantum molecular lens, its filament is attracted into the first filament, and is trapped and guided. The filament is extended and its intensity is boosted high enough to generate a massive amount of white light that saturates the digital camera, as seen in Fig. 2. If the second pulse is further delayed by 50 fs, its filament is completely eliminated.

Our results demonstrate that long range high power laser propagation can be controlled by exploiting the unique quantum rotational behaviour of air molecules.

Reference

1. *Trapping and destruction of long range high intensity optical filaments by molecular quantum wakes in air*, S. Varma, Y.-H. Chen, and H.M. Milchberg, Phys. Rev. Lett., in press (2008).

Contact:
Howard Milchberg, University of Maryland (301-405-4816, milch@umd.edu)

Invited talk at 2008 APS Division of Plasma Physics meeting:
Abstract: NI2.00006 (http://meetings.aps.org/Meeting/DPP08/Event/88567)
Trapping and destruction of long range high intensity optical/plasma filaments by molecular quantum wakes in air, Presenter: S. Varma
Session NI2: Intense Beams, Plasma Filaments, and Nonlinear Waves
12:15 PM–12:45 PM, Wednesday, November 19, 2008, Landmark B