#### Laser Waveguide Technology Could Divert Lightning Strikes



A 2017 NASA study found lightning to be the main driver of US wildfires. (image: rank Cone) Tim Ventura Follow Oct 4, 2020 · 10 min read

Lightning strikes start over 9,000 US wildfires and cause \$5 billion in damages every single year — but a new laser system for creating artificial lightning channels hopes to change that. We're joined by Dr. Jean-Claude Diels, Professor of Physics, Astronomy and Electrical Engineering at the University of New Mexico, who's spent over three decades studying laserinduced lightning discharges with the goal of safely redirecting this powerful force of nature. Jean-Claude, welcome! You've done a lot of research into atmospheric lightning and the laser-stimulated conduction of air. Let me start by asking if you can give me an overview of your research, and I'd also like to ask what inspired you to focus on this area of study?



Dr. Jean-Claude Diels, University of New Mexico (UNM)

What inspired me? I used to fly small planes, and I got hit by lightning while flying, so I thought I should have my revenge. So far, I haven't — and I'm up against stiff competition from European researchers with a level of funding in their project that's considerably larger than what we have here.

To give you an idea, the European <u>Laser Lightning Rod</u> group is planning a field experiment in Switzerland next summer with a grant of about 20 million euro, or around \$24 million US dollars.

Their laser alone will cost 2 million euros after it's fully installed — more than my entire budget of \$100 thousand dollars a year. They're going to be difficult to compete with, but we have slightly different approaches, so I think my team has a shot.

I've read that each lightning bolt contains up to <u>1 billion joules of energy</u>, which

# leads me ask whether your focus is primarily on lightning safety or if you're also considering power generation applications?

The focus is on safety, which is a priority these days due to global climate change and the incredible number of forest fires that are occurring. There are also safety applications for protecting airports, launch pads, and maybe even <u>golf courses</u>. You might be surprised to learn that nearly 5% of all deaths by lightning happen on golf courses when electricity conducts down the club.



An artist's concept of a laser lightning rod on a tall building (EuroNews)

Let's talk about how this laser lightning rod works. In the past, your research involved using an ultraviolet laser to create a "wire in the sky" that safely directs lightning down an ionized air-channel to ground. Is that still the path you're pursuing with your research?

Creating an ionization channel in the air was our initial intent, but nobody has been successful in getting electricity to conduct down it over distances. Yes, we can ionize the air with a laser, but the ionization dissipates before we can trigger the lightning. It goes feet — but we need miles of range.

So, how can we overcome this limitation? One solution appears to be using a laser to

create ionization, which in turn creates a shockwave. Inside of that shockwave, you'll have a column of rarified air, and because it's at low pressure, you'll have created an easier conduction path for the lightning.

# So, in other words, the laser is superheating the air to rarefy it rather than relying on ultraviolet <u>photoionization</u> of a conductive air channel?

Yes, that is exactly the approach that the Europeans are trying to use. Now in my case, I'm trying to use the same rarefaction of air to create a waveguide for a multiple laser system that could still perhaps ionize a column of air.



A schematic of the waveguide approach being used by Diels team.

# Would you envision the laser system being placed on tall buildings and other typical lightning targets to safely conduct this charge to ground?

That's indeed the approach because our laser-based systems are stationary and cannot be moved. Before this, the most successful approach was <u>rocket-triggered lightning</u> <u>discharges</u>. However, what goes up must come down, and you don't want to have the spectacle of having a spent rocket and spools of discharge wire falling back to Earth on a city. I think this takes us into lasers: you've worked mostly with femtosecond-pulsed UV excimer lasers, right? Is that because these are the most efficient ionizers because each photon in the UV spectrum will ionize 1 air molecule?

Yes. I began my work using excimer-gas lasers, but since then I've changed to a type of solid-state laser that's still in the ultraviolet range. The advantage of ultraviolet lasers isn't only the single-photon ionization process, though.

Most researchers are using infrared lasers, but each pulse of light in that spectrum makes little <u>filaments</u> of only 1 millijoule, while in the ultraviolet, the filaments created can be up to 1 joule each.

The European experiment using infrared lasers was able to generate about 1 joule of energy altogether by producing thousands of tiny filaments, but it still creates the desired rarefaction in air, so their team is counting on that to direct the lightning.



A 1kHz filamenting laser installed by Clemens Herkommer for the European LLR project. (Twitter)

So, it comes back to rarefying the air then, and not simply ionizing it. It sounds like rarefaction is the key.

Yes. The past experiments we did showed that the delay between the laser and the lightning was considerably more than the time that it takes for the ionization to dissipate, making this approach unsuccessful.

Since single-beam ionization hasn't worked, there are currently two other approaches being tried. The first involves creating a rarified air-channel, which is what the Europeans are attempting, and then there's my approach, which combines what I call a "waveguide in the sky" with a multiple-beam laser assembly, which I believe will create a continuous conductor where a single beam would not.

The difference between the ultraviolet and infrared approach is that the infrared laser makes thousands of tiny millijoule-energy filaments, whereas the UV approach essentially produces fewer, larger filaments averaging around 0.2 Joule energy per filament.

After getting the laser in place, we need to project a focused, high-intensity beam over a long distance, perhaps around 10 kilometers. The classical solution is to use a huge aperture lens, but given the size required that isn't very practical.

However, there are other ways to focus our beam. One of those involves <u>dynamic</u> <u>focusing</u> — or manipulating the laser so that the beam becomes shorter and shorter, and ultimately compresses to a high enough density to create an ionized air channel. Alternatively, there's also something called an <u>acoustic waveguide</u>, in which the filament creates an acoustic wave that you can use as a waveguide up to one hundred microseconds.



An analysis of the ultrashort pulses used by Diels to generate filamentation.

In the case of the acoustic waveguide, you have to use a very high repetition rate laser to sustain a conductive air channel. My goal is to do this at a frequency of 50 kilohertz using a laser that is frequency triple-compressed, generating a beam that creates filaments of 300 millijoules at 107 picoseconds in the UV.

This is the system we have for our attempt at laser-induced discharge using a laboratory on the roof of our building. Our laser is inside the building, but we can send the beam up from the lab to the roof, and from there we can direct the beam to a rooftop lab, to the top of a nearby mountain, or to any other targets that are accessible in our line of sight.

With our experimental apparatus, we are creating a lightning channel by superheating the air inside the filament, which produces a 40-micron channel within 300 nanoseconds. This channel is essentially an acoustic shockwave that becomes permanent at a repetition-rate over 10 kilohertz, and our apparatus is designed to achieve a rate of 50 kilohertz.

For this test, we built a laser out of parts salvaged from the trashcan at the Air Force research lab in Albuquerque, where we found five laser skeletons that met our

specifications. It was a challenging task to build one laser out of five skeletons, but it's working now and produces an 80 Watt beam at 50 kilohertz that is pumping an amplifier for the filamenting laser.



Local Facility Distance: 40 to 100 meters

Remote Target Distance: ~22km

Before we go further, could you describe for us what you mean by the term filament? Could we describe this as a channel in the air that the beam is traveling down as it propagates?

Yes, <u>filamentation</u> is the propagation of the beam through the air without diffraction. Now, during our early attempts to create a single-beam ionization channel, we found that sending the laser beam to a distance of even one kilometer leads it to spread out too much. For instance, if you start with a one-millimeter diameter beam, it will spread out to a few meters after one kilometer, and the energy is totally dissipated in the air.

However, if you have a high enough beam intensity, the air will begin to act as a lens, and the laser beam will self-focus. At that point, when the air starts to ionize, the electrons tend to counteract that focusing and this creates what is essentially a waveguide in the air.

This initial channel only lasts for a few microseconds, but it creates an acoustic shock wave when it dissipates that continues to act as a waveguide and lasts for a much longer

period of time. This is the effect we're trying to exploit by taking our repetition rate to 50 kilohertz.

### So, what you're describing sounds like a waveguide made out of shockwaves. In this case, is the filament itself a shockwave?

Yes, but keep in mind there are two filaments: the first is self-focusing weakly ionized air, and the second is a shockwave with a longer duration. These two continue in a cycle at 50 kilohertz, one creating the other, and the result is a stable conduction path through the air.

Now I haven't touched much on your teaching work, but I understand that you've graduated over 50 students with specialization in various areas related to high-speed pulsed lasers. Are any of your students following in your footsteps in terms of your work with lightning and atmospheric conductivity?

One of my students went to work for a project in Romania, the <u>Extreme Light</u> <u>Infrastructure</u>, which boasts having the largest laser in the world. His budget just to build the laser was 310 million euros.

The US is trying to compete by giving \$10 million to the <u>University of Michigan</u>, but this is kind of ridiculous proportion. Altogether, the total budget for the Extreme Light Infrastructure project is 855 million euros, and we're not going to effectively compete with that on a budget of \$10 million.



The Extreme Light Infrastructure beamlines building, boasting the world's most powerful laser. (ELI)

#### So, your student is working on a project in Romania, and then you also mentioned another European team. Can you tell me about them?

Yes. Now, this team has a really huge facility. You see the gigantic building once the French team is making a laser it's a French & Swiss team. They're making a laser of that they plan to bring to a peak in the Alps. You can learn more about them on their website, which is online at <u>http://llr-fet.eu/</u>

You're working with solid-state lasers now, right? Back in the old days, I understand this research was done with massive excimer gas lasers, but if I understand things correctly you're working with something like a 355-nanometer solid-state laser, right?

Yes. Solid-state lasers can be considerably smaller than gas lasers, and if you want to build a device that you can move to the top of a mountain, it needs to be as small and compact as possible. However, excimer gas-lasers are still used in some cases.

For example, there's an institute in Moscow is doing similar research with a gigantic excimer laser that takes up a whole building — but the Russians are not applying this

research to lightning like my team or the Europeans are.

How will you identify where the lightning is in order to point the laser at it? I understand that the laser creates a conduction path, but in order for conduction to happen you need to know where the lightning originates. Do you have a way to identify where to shoot the laser in the clouds?

Identifying where to send the beam is something that will require a large, multidisciplinary team. This is a resource that the European project has, and they're well-positioned to design equipment to detect where the lightning is going to start.

However, this is an area that still requires a lot more research before we fully understand it. You can't simply shoot a laser into the nearest cloud and expect results. Clouds are big, and we don't know exactly where the field strength will be highest in them. We still need to find better ways to measure that.

#### About Our Guest

Jean-Claude Diels received a Ph.D. degree in 1973 from the University ofBrussels, Belgium, for his research on coherent pulse propagation performed at the University of California, Berkeley, under advisement of Prof. E. L. Hahn.

He is currently Professor of physics and electrical engineering at the University of New

Mexico, Albuquerque. He has graduated over 50 students in various areas including coherent interactions, ultrashort pulse generation and diagnostics, nonlinear propagation of intense pulses, and laser-induced discharges.

He co-authored with Wolfgang Rudolph the graduate textbook Ultrashort Laser Pulse Phenomena: Fundamentals, Techniques and Applications on a Femtosecond Time Scale and with Ladan Arrisian the book, Lasers: The Power and Precision of Light, celebrating the 50th anniversary of the laser, and published 5 book chapters.

Dr. Diels has been honored with a fellowship in the Optical Society of America, and is the recipient of the 51st Annual Research Lecturer Award (April 2006), and of the 2006 Engineering Excellence Award of the Optical Society of America. You can learn more about him online at his <u>website</u>.