Lightning control by lasers

Powerful lightning strikes pose a significant threat to buildings and people, but imagine if it were possible to control and direct them with a laser beam. *Nature Photonics* spoke to Jérôme Kasparian, a researcher from the University of Geneva and co-ordinator of the Teramobile project, about the idea.

The idea of firing an intense laser beam into a thundercloud to induce lightning and guide it back to a preferred location on the ground may sound far-fetched, but such a practice could one day be commonplace for protecting important buildings such as power plants or airports. In recent years, European scientists working on the Teramobile project (see Box 1) have demonstrated that intense, ultrashort laser pulses can ionize the air to create a virtual conductive path for guiding an electrical discharge along a straight line of several metres in a laboratory. The next stage is to build a laser 10 times as powerful, 'Teramobile 2', which, it is hoped, will allow a similar effect high in the sky. *Nature Photonics* spoke to Jérôme Kasparian about progress so far.

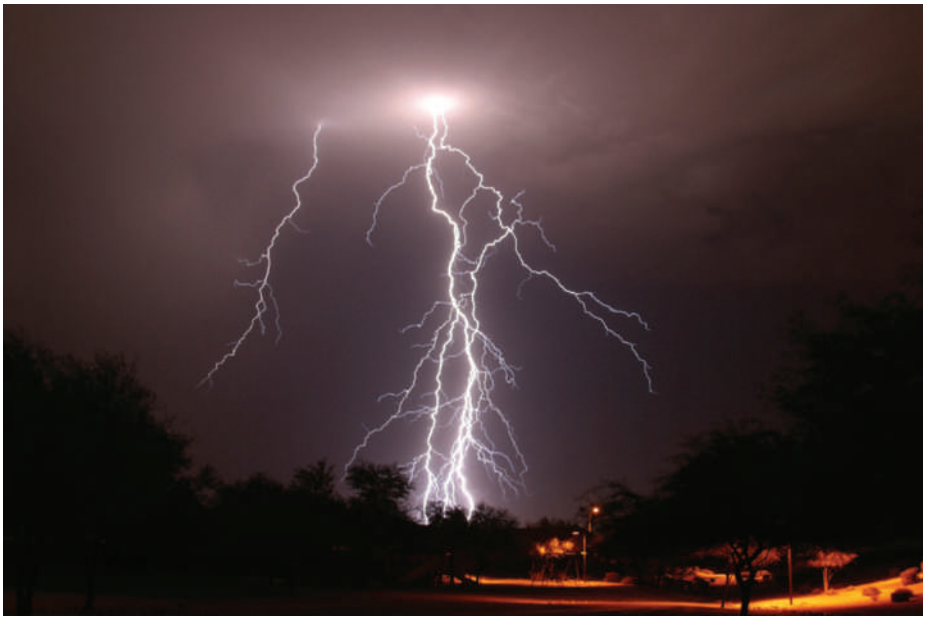
How did the idea for using lasers for controlling lightning come to mind?

This idea of triggering lightning using lasers is almost as old at the laser itself. Before long there were laser powers sufficient to ionize the air, and early on people realized that this would create a conducting path for electrical charge which could assist the triggering of lightning.

The first attempts took place as early as the 1970s in Russia and Japan, using huge CO_2 lasers, strongly focused, which generated a plasma spark but were not very successful. The problem was that the plasma was very localized and strongly absorbed the laser energy, thus preventing further propagation and the creation of a long ionization channel. There were a lot of laboratory experiments; in addition a Japanese team tried an experiment in the atmosphere in real conditions with three huge lasers focused near the top of a lightning tower. However, this was a huge system and not very effective.

What helped the idea to become more realistic?

What has happened between the early studies and now is the advent of CPA [chirped pulsed amplification] lasers, which allow the creation of ultrashort and high-power pulses beyond the terawatt level. They allow a self-guiding propagation regime known as filamentation. In this regime there is a dynamic balance between the nonlinear Kerr effect (self-focusing) and the effect of free electrons, which have a negative contribution on the refractive index and tend to defocus the beam. This gives a balance between the self-focusing and defocusing of the beam, resulting in self-guiding. With a sub-joule laser it is possible to make filaments tens or even hundreds of metres long with an electron density of 10^{15} or even 10^{16} electrons per cubic centimetre. Today, there are several groups working on similar ideas using different configurations, including the group of Pépin and Mercure in Quebec, the group of Diels at the University of New Mexico, and our Teramobile group, which is a European collaboration. Everyone is working on the idea of having a long ionized channel that can trigger and guide discharges. Several groups have been doing small-scale experiments over a few centimetres or few tens of centimetres, and then there have been very impressive experiments by the group in Quebec. We have also done some experiments in the lab using real filaments over a few metres at a few megavolts, as well as conducting field trials.



© ISTOCKPHOTO.COM/AJPHOTO

In the future, intense lasers may be able to provide control of electrical activity inside thunderclouds. Experiments in the laboratory and field trials have shown in principle that this is feasible, but more powerful lasers are needed to actually trigger and guide lightning.

My understanding is that the principle of using lasers for lightning control has been well demonstrated in the lab, but what about field trials?

It is not really straightforward going from the lab to the field. A big issue is with the lifetime of the plasma you generate. It is limited to the microsecond range. The discharge establishes at a speed of typically a few metres per microsecond, which means that after the discharge has propagated a few metres the track has disappeared. As a consequence, the pulse duration limits the effective length of the channel. We took our laser and went to the Langmuir Laboratory of New Mexico Tech, which is a permanent station for lightning studies. The visual observation did not give any results because we were at pretty high altitude at 3,000 metres and in the clouds at that time, and the camera could not see anything, but we could use the lightning mapping array of Langmuir Laboratory, a network of radiofrequency detectors. Any discharge radiates a broad spectrum of radiofrequency radiation which can be detected. There were thirteen detectors spread over the region and we used the five closest to our lasers. These detectors detect precisely the time of arrival of each laser pulse and by triangulation you can reconstruct the three-dimensional position of each event. You have to remember that this detection technique detects not only the lightning strike but all of the electric activity in the cloud. What we did was to correlate the electric activity with the position of the laser beam and the time when the laser was pulsed with a precise repetition rate of 10 times per second. We were able to correlate an excess of electrical activity with the location and time of the laser pulses. These events correlated with the laser are quite faint events; they are not actually lightning strikes.


CNRS PHOTOTHÈQUE / CLAUDE DELAHAYE

Jérôme Kasparian, leader of the Teramobile team, adjusts the beam path of the Teramobile laser.


© 2003 AAAS

Image of a high-voltage electrical discharge, that is, artificial lightning, over a distance of 3 m with (straight path) and without (erratic path) the assistance of a guiding laser filament.

So what's next?

The main limitation to overcome is the limited lifetime of the plasma channel. We need to get an effective channel length of a few tens of metres to trigger the lightning. This length scale has been confirmed by experiments using rockets with conductive wire tails of various lengths. Such a short channel would also be better for us because we don't want to have the channel come all the way down to the laser from the point of view of the damage to the equipment or us — we are sitting underneath in the laser control room. To create plasma channels with a length of a few tens of metres, we need a more powerful laser. We are working on Teramobile 2, which will be a 10 times more powerful laser. However, it is not only a matter of brute force; we are also trying to be cleverer and not just shoot 10 times more power but organize this power in a train of 10 pulses, sharing the full power of the laser. The idea is that the first pulse would better establish the channel and the subsequent ones would maintain it. The burst mode will be something very innovative, as will a mobile laser providing 30 TW pulses. We will benefit from the fact that CPA technology has improved a lot in the past 10 years, so we can simply get more power from the current CPA technology. The technology is evolving towards smaller systems, especially with diode-pumped lasers. Most of the size of the systems is due to the pump lasers. From the energy point of view it is pretty inefficient. Eventually, I guess that there will be directly diode-pumped femtosecond systems. You can really imagine that in a few years the laser technology will allow us to have such a mobile terawatt laser in a van. It is hard to say exactly when Teramobile 2 will be ready, but I guess it is a matter of a few years.

Box 1 | The Teramobile project

The Teramobile laser project was launched in 1999 and became operational in 2001. It is a very powerful mobile terawatt-class Ti:sapphire laser which uses chirped pulse amplification to generate intense ultrashort pulses (see specifications below) for atmospheric studies. The laser comprises a Ti:sapphire oscillator and a Nd:YAG pumped Ti:sapphire amplification chain made of a regenerative amplifier and two four-pass amplifiers. It concentrates the state-of-the-art laser technology in a 20-foot standard freight container, allowing field measurement campaigns. It is an international project initiated jointly by a French–German collaboration of CNRS (France) and DFG (Germany). Switzerland has now joined the consortium. It is now funded by ANR and the Swiss FNS and involves five research institutes in Berlin, Dresden, Lyon, Palaiseau and Geneva. The laser system itself was built by Thales Laser of France. The Teramobile laser is used for investigating nonlinear propagation of femtosecond-terawatt laser pulses over long distances in the atmosphere, and their applications to atmospheric research. This includes Lidar remote sensing of atmospheric pollutants as well as lightning protection and triggering by a mobile terawatt laser system.

Teramobile specifications

Centre wavelength: 800 nm
Pulse energy: 350 mJ
Peak power: 5 TW
Pulse duration: 70 fs to 2 ps
Repetition rate: 10 Hz
Output beam diameter: 50 mm
Size: 3.5 m × 2.2 m
Weight: 10 tonnes

How could you ensure that the discharge doesn't come directly back to the laser itself?

In fact this is not a big problem because you can control the distance from which the conducting channel begins. If you insert a grounded conductor in the laser path before it gets back to the laser, the discharge will go to this component. There are two variants. One is to use a grounded metallic mirror to reflect the beam and the discharge will go to the ground through the mirror; or you aim with the laser via the top of a classical lightning rod so that the discharge will go to the rod instead of following the conducting beam.

What are the benefits of using lasers for controlling lightning over schemes such as using rockets with conducting tail wires?

The rockets work pretty well — every second shot can be effective. However, you have a limited number of rockets and you cannot easily aim at the place in the clouds that you want to activate. With a laser, you can aim it and work it continuously so it would provide much more flexibility. Although a laser scheme might be too expensive for individual homes, for critical facilities such as power plants or airports it could be used to direct a laser strike away to a preferred location. Of course this is in the longer term.

INTERVIEW BY OLIVER GRAYDON