Trampoline mirror may push laser pulse through fabric of the Universe

Enlarge / Pictured: Definitely *not* a possible universe-altering fancy trampoline.
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Scientists want to rip the Universe apart. At least that is what a *Daily Mail* headline might read. Lasers can now reach power in the petawatt range. And, when you focus a laser beam that powerful, nothing survives: all matter is shredded, leaving only electrons and nuclei.

But laser physicists haven't stopped there. Under good experimental conditions, the very fabric of space and time are torn asunder, testing quantum electrodynamics to destruction. And a new mirror may be all we need to get there.

On average, the amount of power used by humans is about 18 terawatts. A petawatt is 1,000 times larger than a terawatt. The baddest laser on the planet (currently) produces somewhere between 5 and 10 petawatts, and there are plans on the drawing board to reach 100 petawatts in the near future. The trick is that the power is not available all the time. Each of these lasers produces somewhere between 5-5000 J of energy for a very very short time (between a picosecond—10^{-12}s—and a few

femtoseconds—10^{-15}s). During that instant, however, the power flow is immense.

Numbers beyond 42

The numbers get even more mind blowing when you consider that all of that energy is focused, such that the intensities reach something like 10^{22}W/cm^2. To put this in perspective, you start creating a plasma when intensities hit 10^{12}W/cm^2. Once intensities get above 10^{25}W/cm^2, if the light hits just a single electron, there's enough energy to cause $e=mc^2$ to start a cascade of electron-positron production out of the vacuum. If the laser intensity hits 10^{29}W/cm^2, not even that single electron is required—the light will rip virtual electrons out of the vacuum, generating real charges from the apparent nothingness of empty space.

But getting to 10^{25}W/cm^2 is tough. The issue is one of material. Or, rather it's the lack of a material that can survive long enough to focus the laser light. This is where plasma mirrors come in.

Plasma mirrors were all the rage a few years ago when petawatt lasers were all fresh and new. The idea is actually very simple. A plasma is a gas of conducting particles, with its electrons being very light and easy to move around. When light hits the plasma, the electrons are accelerated back and forth, following the light's electric field. In doing so, the electrons absorb and re-emit the light in the opposite direction. In other words, the light reflects from the plasma, just like it does from a chrome bumper.

A plasma is basically already as destroyed as a material can be, so the laser beam cannot damage the plasma.

It was initially thought that plasma mirrors could not act as

a good focusing element, though. Essentially, it is impossible to get the shape right. But 24 hours of supercomputer time has shown that a plasma mirror might be the right way to go. New developments in model code allowed researchers to simulate a full 3D laser pulse impacting on a surface. Researcher Henri Vincenti from France has taken advantage of these computational developments to adapt this code to open up new ways to increase the intensity of some very bright lasers.

Vibrating into focus

In his model, the surface was placed at an angle to a laser beam. A laser beam has an intensity profile that is highest in the center and fades off to the outside. Combine the intensity profile with the angle of the surface, and the plasma generated by a laser pulse forms a relatively smooth elliptical shape. This means that the light reflected from the plasma will focus to a well-defined point.

That is nice, but what follows is even better. As the light intensity gets really high, the collective motion of the electrons starts to look a bit like the motion of the woofer on a speaker. The light is essentially hitting a surface that is vibrating super fast. That motion Doppler shifts the light to higher frequencies (like the siren on an approaching ambulance). An incident beam of red light will be reflected with strong blue and ultraviolet components.

The way the mirror oscillates also means that the light frequencies are all multiples of each other. The mirror reflects all these colors together, and they add up to a pulse that is even shorter in time. In fact, the pulse goes from being 20fs in duration to 0.1fs (a femtosecond is 10^{-15}s). This by itself increases the intensity by a factor of 100. The shorter wavelengths also means that the light focuses to a smaller spot.

The end result is a factor of 1,000 higher intensity for the same input laser and a simple mirror swap. That is pretty cool.

Will it work in reality? I think so. The code to model high power laser pulses hitting stuff is pretty good now. The technical details are not too challenging: use a low power terawatt laser pulse to create the mirror and then hit it with everything you've got a few picoseconds later. That is bread and butter to a high power laser labs.

Then, of course, they can all stare in wonder at the hole they had made.

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