Energy shifting

Nature Photonics spoke to Kim Ta Phuoc about an extremely bright and compact X-ray and gamma-ray source that exploits laser plasma acceleration and Compton scattering simultaneously.

Why do we need gamma-ray sources?

There are many applications of gamma-ray sources for industrial, non-destructive testing. There are also projects with the USA Department for Homeland Security for screening containers. There are medical applications of gamma-ray sources in radiotherapy, as well as a number of purely scientific applications. Each of these requires a source with different properties. The most common are radioactive sources, which can deliver photons with energies up to about 2 MeV, and Bremsstrahlung sources based on electron accelerators, which deliver photons up to the maximum energy of the electrons. Sources based on radioactive materials are very compact but you cannot turn them off and there are some safety issues concerning storage. They also cannot be tuned in wavelength; if you want a different energy, you must use a different source. Bremsstrahlung sources can produce high-energy radiation but have limitations in terms of size and spectral width. Sources based on inverse Compton scattering are tunable but require large-scale conventional accelerators to produce gamma rays.

KIM TA PHUOC

Left to right: Antoine Rousse, Kim Ta Phuoc, Sebastien Corde and Amar Tafzi.

How does your source work?

In our source, X-rays and gamma rays are produced when a relativistic electron bunch collides with an intense laser pulse. During the collision, photons from the laser are absorbed by the relativistic electrons and then emitted, through inverse Compton scattering, at X-ray or gamma-ray wavelengths. These high-energy photons are produced from the laser's optical photons because of two large Doppler shifts. One is the shift in laser frequency seen by the rapidly moving electrons, and the other is a frequency shift of the photons emitted from these electrons.

Our source is different from other techniques because it is entirely optical. We accelerate the electrons in a laser plasma accelerator while simultaneously focusing an intense laser, typically with a power of a few tens of terawatts, into a helium gas jet. When the laser propagates through the gas, it drives, in its wake, an accelerating plasma structure in which the electrons can be trapped and accelerated at 100 MeV mm^{-1}. The laser pulse is then back-reflected by a foil placed at the exit of the jet, where it collides with the accelerated electron bunch to produce an intense burst of X-rays and gamma rays.

Many researchers have tried to achieve this feat using two laser beams, but have struggled owing to alignment difficulties. In contrast, we employ just one beam and use a foil to back-reflect the laser pulse. Most of the laser energy is reused and an overlap with the electron bunch is guaranteed. We used a 50 TW laser, which requires an area of around 50 m^2. However, this could easily be decreased because laser plasma acceleration can be achieved using lasers that are smaller and cheaper than the one employed in our study.

What about brightness and tunability?

The peak brightness of our source is very high, for several reasons. The duration of the radiation flash is short — just a few femtoseconds. The transverse size of the source is of the order of 1 μm, which is also very small. The number of photons per burst (10^8) is not exceptional but is close to what could be achieved through betatron or Bremsstrahlung approaches. The high peak brightness of our source is therefore primarily due to the short pulse duration and the small source size. The output spectrum of our source is broadband because our electron kinetic energy spectrum is broadband. However, using tunable, nearly mono-energetic electrons would allow us to produce tunable, nearly monochromatic radiation. Technologically this is not a problem because we have experience in producing such electron beams. Adjusting the electron energy can be used to control the energy of the radiation. In our regime of laser plasma acceleration, we can tune the electron energy from around 20 MeV to 200 MeV, and thus could produce electromagnetic radiation from around 10 keV to 1 MeV. However, the Compton scattering spectrum would not be very narrow in this case, owing to the angular divergence of the electrons.

What's the next step?

We want to produce tunable, nearly monochromatic radiation and extend the spectrum to the few mega-electronvolt regime. We also want to reproduce this source in a smaller system — the goal being to produce X-rays at a higher repetition rate for use as a compact femtosecond X-ray source. Finally, we would like to demonstrate this technique using higher-energy lasers that have longer pulses, such as those used in fusion research.

INTERVIEW BY DAVID PILE

Kim Ta Phuoc and colleagues have a have an Article on creating X-rays and gamma rays from a compact and bright source on page 308 of this issue.