5–6 Relativistic Harmonics from Tenuous Plasma

— Discovery of a New Compact Coherent X-ray Source —

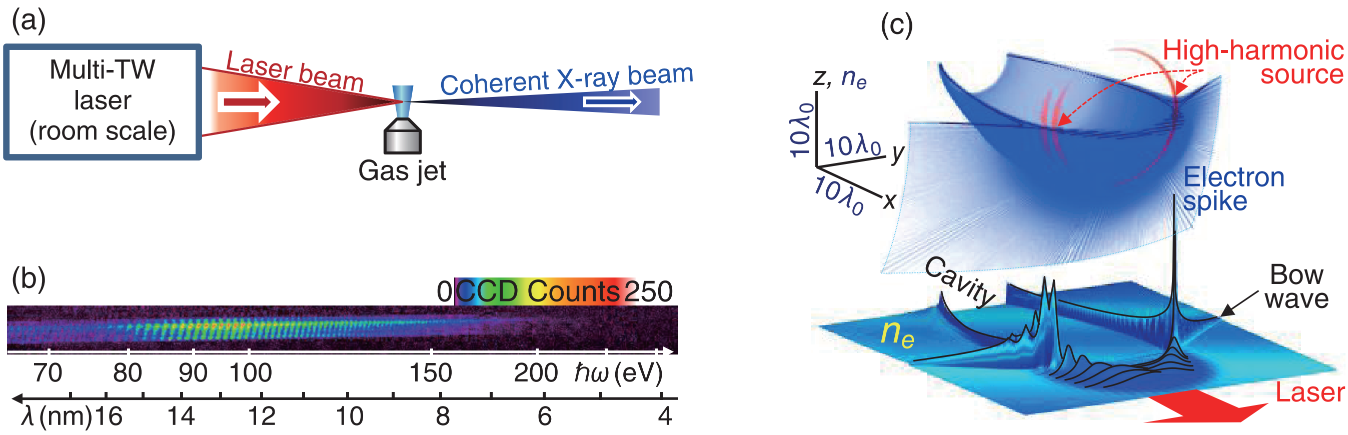

Fig.5-14 New regime of high-order harmonic generation by relativistic laser focused onto gas jet target
(a) Experimental setup. (b) Typical single-shot raw data. (c) 3D PIC simulations demonstrating electron density spike at the joint of the boundaries of the wake and bow waves and location of high-harmonic source.

Bright X-ray sources are necessary for fundamental research and applications in the life sciences, material sciences, nanotechnology, and other fields. The ultimate performance requires temporally and spatially coherent X-ray pulses that are compressible to the shortest durations, focusable to the tiniest spots, and capable of producing fine interference and diffraction patterns. Two broad classes of bright X-ray sources are available, those based on large-scale accelerators (synchrotrons, X-ray free-electron lasers) and those based on compact lasers (e.g., laser plasma X-ray emission, plasma-based X-ray lasers, atomic high-order harmonics, and betatron sources). The great advantages of the laser-based sources are their accessibility for university-scale laboratories and their ultrashort pulses with durations from picoseconds down to <100 as (10^{-16} s). However, because of fundamental limitations, it has been overwhelmingly difficult to achieve laser-based bright coherent X-ray sources with keV and especially multi-keV photon energies. Our aim is to develop a new generation of such sources to create new fields of fundamental research and applications.

We discovered a new regime of high-order harmonic generation by high-power (10–200 TW) relativistic irradiance (>10^{18} W/cm^2) femtosecond lasers (~30–50 fs) focused on gas jet targets, as shown in Fig.5-14(a). Comb-like spectra with hundreds of even and odd harmonic orders (Fig.5-14(b)), reaching a photon energy of 360 eV, including the "water window" spectral range, were generated by either linearly or circularly polarized pulses from the J-KAREN (KPSI, JAEA) and Astra Gemini (CLF, RAL, UK) lasers. A 120 eV harmonic contained up to 4 × 10^9 photons. Using particle-in-cell (PIC) simulations and mathematical catastrophe theory, we introduced a new mechanism of harmonic generation by sharp, structurally stable, oscillating electron spikes at the joint of the wake wave and bow wave boundaries, as shown in Fig.5-14(c).

Our compact bright coherent X-ray source can be built on a university-lab-scale repetitive laser and accessible, replenishable, and debris-free gas jet target. Importantly, the photon energy and number of photons are scalable with the laser power. This will affect many areas of fundamental research and applications requiring a bright X-ray/extreme ultraviolet source for pumping, probing, imaging, or attosecond science.

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Reference

Pirozhkov, A.S. et al., Soft–X–Ray Harmonic Comb from Relativistic Electron Spikes, Physical Review Letters, vol.108, issue 13, 2012, p.135004–1–135004–5.