Superradiant light sources based on plasma accelerators in the nonlinear blowout regime

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Coherent light sources, such as free electron lasers, provide bright beams for biology, chemistry, physics and advanced technological applications. As their brightness increases, these sources are also becoming progressively larger, with the longest being several km long (e.g. LCLS). Plasma accelerators, are much more compact, and can play a key role in bringing these sources to smaller laboratories. Reaching this goal requires orders of magnitude increase on the brightness delivered by plasma accelerator-based light sources. A radical enhancement of beam brightness in plasma accelerator light sources depends directly on the onset of temporal coherence and superradiance.

Here, we propose a new radiation emission mechanism that may bring temporal coherence and superradiance to plasma accelerator-based light sources, without the onset of the so-called free-electron-laser instability [1]. The mechanism is suitable for experimental demonstrations in current plasma accelerator laboratories. Instead of focusing on single particle motions, we investigate the radiation produced by an ensemble of light-emitting particles exhibiting collective, matter-wave effects. Such collective motions, which can be as simple as a plasma wave, are pervasive in plasmas and plasma-based accelerators. We find that the trajectory of the centroid of such collective perturbation (which we denote as a quasi-particle) determines key radiation aspects, such as temporal coherence, just as if it were a single particle undergoing a similar trajectory. We apply this concept to obtain superradiant emission using relativistic electron bunches, and in plasma accelerator based-light sources, in order to generate broadband and narrow bandwidth superradiant and temporally coherent radiation in the XUV/soft-xray region. We use theory and particle-in-cell simulations complemented by the Radiation Diagnostic for Osiris (RaDiO) [2,3].
As an example, we explore a realization of this quasiparticle radiation concept in the nonlinear blowout regime. The dense electron spike that characterises the back of the nonlinear plasma wave plays the role of the radiating quasiparticle. Plasma density ramps and corrugated plasma profiles control the trajectory of the electron spike quasiparticle, and thus its radiation properties. Figure 1 shows an example of Cherenkov emission emitted by superluminal quasiparticles in a plasma density up-ramp. The radiation consists of optical shocks formed at the Cherenkov angles associated with the velocity of the first three nonlinear wake electron spikes. Radiation interferes constructively at the Cherenkov angle. Each optical shock is a broad-band single cycle pulse. The peak radiation intensity increases quadratically with propagation distance, or, conversely, with the number of particles that contribute to its radiation, as in superradiant emission [1].
Instead of considering a nonlinear plasma wave, which would provide radiation up to the xUV, the first experimental demonstration of this concept used superluminal ionisation fronts to produce THz radiation in air [4].

References
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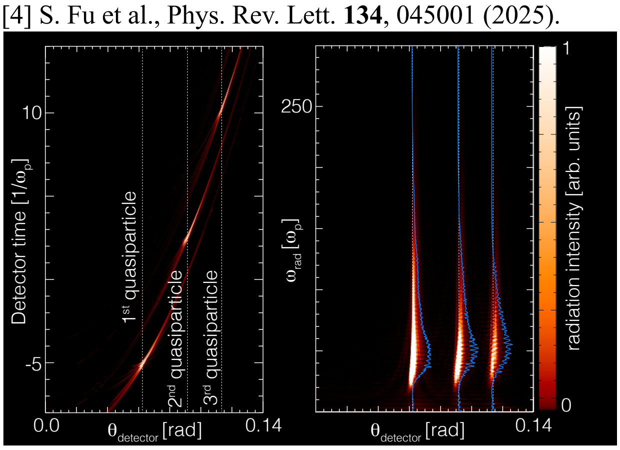

Figure 1.
(right) Radiation emission by a superluminally moving dense electron spike quasiparticle in the nonlinear blowout regime in a spherical radiation detector placed in the far field. (left) Corresponding radiation spectra. Simulation results obtained with Osiris [2] and RaDiO [3]