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Superradiance and temporal coherence in the non-linear blowout regime

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Well known light emitting mechanisms (e.g. betatron radiation and non-linear Thomson scattering) are based on the motion of single-particles. Experiments demonstrated that these mechanisms can lead to the emission of bright radiation bursts, with frequencies extending up to the x-rays and beyond. These sources have intrinsic limitations: the electron velocity is always lower than the speed of light, and the acceleration that can imparted to an electron is not arbitrary.

Here, we consider instead the radiation emitted by collective excitations such as plasma waves. We show theoretically that the trajectory of the centroid of a plasma fully determines the temporal coherence features of the emitted radiation, just as if it were a real particle executing the same trajectory. A key feature of this concept is that the trajectory of a collective excitation such as a plasma wave can be arbitrary: it can go faster than light and have arbitrarily large accelerations. Instead of relying on electric and magnetic fields to accelerate particles, these features are a result of a coordinated reorganisation of the light emitting medium.

To illustrate the concept, we performed 2D and 3D simulations using the particle-in-cell code OSIRIS (including the Radiation Diagnostic for OSIRIS - RaDiO) to purposefully design wave trajectories which are inaccessible to single particles, with both examples of broadband and narrow band emission. We show that a superluminal laser/plasma wakefield will generate an optical shock at the Cherenkov angle. The emission is superradiant for all frequencies, thus potentially leading to a plasma-based source of temporally coherent broadband radiation. In contrast, a laser propagating in a sinusoidally modulated plasma density profile results in a periodic motion of the plasma wave centroid that results in temporally coherent narrow-band emission. Here we observe the generation of temporally coherent harmonics at the double doppler shifted frequency of the plasma wave centroid trajectory. This leads to a narrow frequency spectrum and to temporally coherent emission up to 100-1000 times the plasma frequency.

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