Superradiance from superluminal nonlinear plasma wakefields

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Bright tunable radiation has applications ranging from biomedical applications to fundamental processes of light-matter interaction. One of the experimental concepts that is most used today is the free-electron laser, an ultra-bright, frequency tunable synchrotron light source, that requires expensive and bulky hardware.

In this work, we propose a new superradiant radiation source using wakefield acceleration structures, driven by either ultra-short laser beams or highly energetic particle beams. In both cases the interaction with plasma leads to a highly nonlinear regime (called bubble/blowout regime), in which the plasma electrons are expelled from the axis, creating a nearly complete blowout. In such structures, radiation is typically produced by the betatron oscillations of electrons injected into the blowout bubble. However, the wakefield itself also radiates in the nonlinear regime: the back of this blowout bubble is characterized by an accumulation of relativistic electrons that can radiate well above the plasma frequency. A plasma density up-ramp forces the back of the bubble to travel superluminally. Even though individual electrons are subluminal, the collective motion at the back of the bubble is akin to a particle moving faster than c. The superluminal structure produces superradiant optical shock[1] at the Cherenkov angle.

We use the PIC code OSIRIS[2] and the Radiation Diagnostic for Osiris (RaDiO)[3] module to show that such superluminal structures lead to superradiant emission at the Cherenkov angle. First, we use 2D simulation data with a superluminal external field to showcase the method. Secondly, we use 3D simulations of both LWFA and PWFA that exhibit the desired behavior. We also describe the radiation spatiotemporally.

References

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