Superfluorescence (collective spontaneous emission) observed from helium atoms following excitation using an extreme-ultraviolet free-electron laser

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Synopsis Using numerical simulations, and experiments at a free-electron laser, we have studied superfluorescence emission in helium atoms at visible wavelengths, and also observed strong directional emission at extreme ultraviolet wavelengths.

Superfluorescence is a collective emission process which can occur when a sufficiently dense excitation is created in an atomic medium sufficiently rapidly. It has been observed following excitation at visible wavelengths in a range of systems. We recently demonstrated that it can occur following excitation at extreme ultra-violet wavelengths in helium, using the Spring-8 Compact SASE Source (SCSS) free-electron laser (FEL) tuned to a central wavelength resonant with 1s1s (ground state) to 1s3p excitation. Strong superfluorescence was observed on the 1s3p-1s2s transition, at 502 nm [1]. Detection of the emitted pulses with a streak camera revealed picosecond pulses (figure 1) with delay and intensity scalings characteristic of superfluorescence.

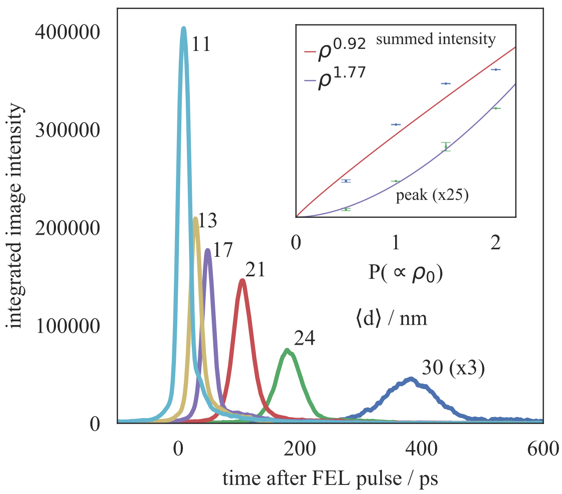

Figure 1. [1] Averaged streak camera traces of superfluorsecence on the 1s3p-1s2s transition (502 nm) at different gas densities. The inset shows the ρ_0^2 scaling of the peak intensity (ρ_0 is the ground-state number density). ⟨d⟩ is the average interatomic spacing.

At higher gas densities superfluorescence emission was also observed on the 1s3s-1s2p (728 nm) and 1s3d-1s2p (668 nm) transitions [2]. At an FEL wavelength resonant to 1s4p excitation, superfluorescence was observed on the 1s3d-1s2p transition only [3]. Simulations of the excitation process and the subsequent development of superfluorescence broadly agree with the observed gas density dependence of the results [4], and simulations using 161 levels [5] suggest the involvement of many excited states (figure 2). Using an X-ray streak camera we have also observed directional EUV emission, and compared this to the results of simulations of the propagation of SASE pulses through dense atomic helium. Experiments are planned to observe two-photon induced superfluorescence at EUV wavelengths.

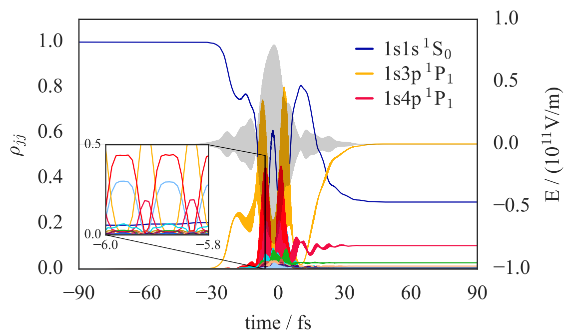

Figure 2. [5] Single-atom simulation, beyond the rotating wave approximation, of the excitation of helium atoms by a 30-fs-long SASE pulse with characteristic phase noise. Excited states other than the resonantly-coupled 1s3p state are significantly excited.

References

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