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Mapping out the dynamic growth rate of the self-modulation instability

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The self-modulation instability (SMI) is instrumental for single-stage plasma wakefield accelerator concepts with long, high-energy drive bunches such as the AWAKE experiment. It provides a self-consistent mechanism to reach high-amplitude wakefields despite the driver's length, which would otherwise not excite the plasma resonantly.

Recent experimental demonstrations of acceleration with a self-modulated proton driver have confirmed that longitudinal variation in the plasma density profile can effectively delay or hasten the growth of the SMI [1, 2], as previously predicted with theoretical asymptotic models [3] and with particle-in-cell simulations [4].

By reframing the problem in terms of detuning effects and seed frequencies, we present a new framework for understanding the link between the plasma density and the development of the SMI, particularly at its onset. This approach allows us to map out the instability's amplitude response (or growth rate) as a function of the perturbation frequency, and reveals surprising properties of the SMI. This work may have important implications for the control of the SMI and the associated acceleration process.

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