A Wave-Based Model for Cross-Beam Energy Transfer in Inhomogeneous Plasmas

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University of Rochester, Laboratory for Laser Energetics

Summary

A 3-D wave-based model of CBET* has been successfully developed in *LPSE*

- This model solves the time-enveloped Maxwell equations in 3-D coupled to a fluid equation for the low-frequency ion-acoustic response
  - radiative boundary conditions, arbitrary incident beams
- A solid understanding of CBET has been obtained on OMEGA
  - coordinated program of theory, numerical simulations, and experiments
- CBET mitigation is a crucial part of LLE's 100-Gbar plan

TC12767

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The boundary conditions use a "total-field/scattered-field" formulation together with a perfectly matched absorbing layer (PML)

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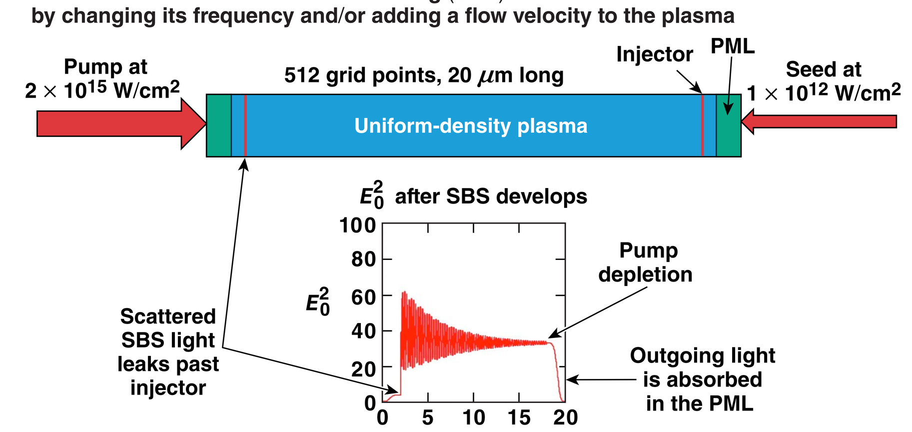

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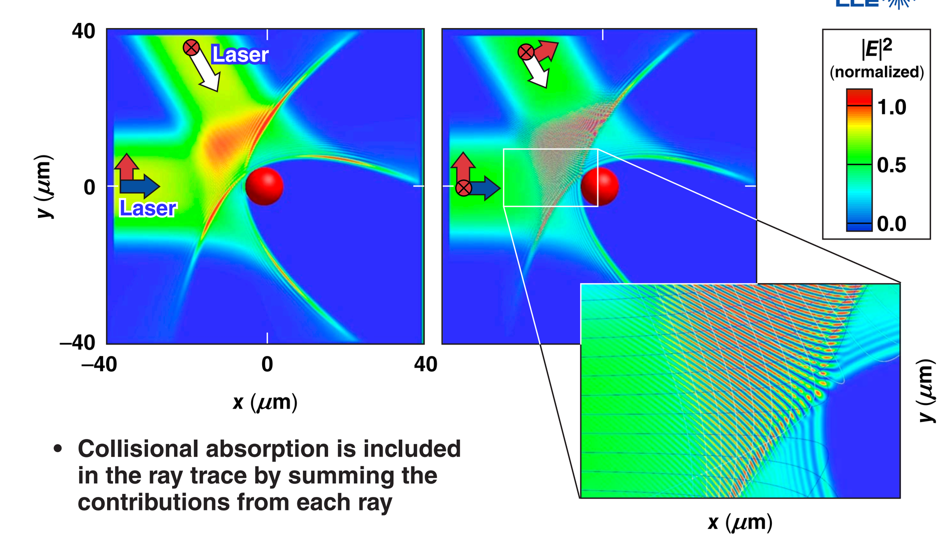

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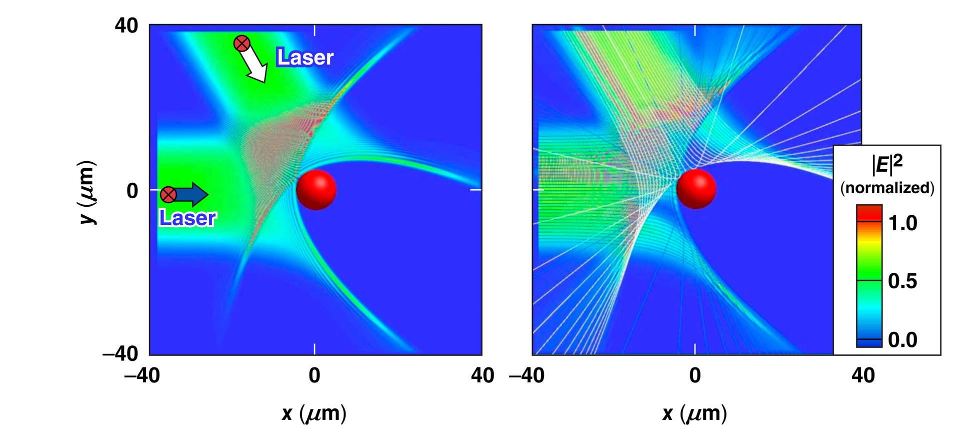
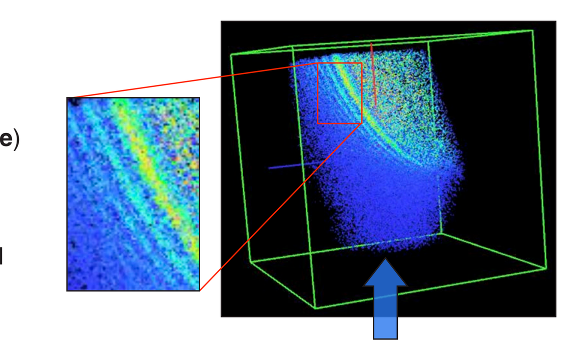


TC12776

A wave-based CBET model is required for several important reasons

- There are uncertainties associated with ray-based CBET models that are hard to quantify without comparison with a more-fundamental model
- The model's correctness is empirically determined; however, experimental tests of CBET are integrated experiments (indirect)
- Caustic surfaces/turning points (field swelling, Airy-like patterns)
- Beam speckle (spatial and temporal incoherence)
- Polarization effects
- The IAW response is approximate in ray-based CBET (steady state, strong damping)



TC12777

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- Absent nonlinearity, the geometric-optics approximation is well justified based on the long plasma scale lengths
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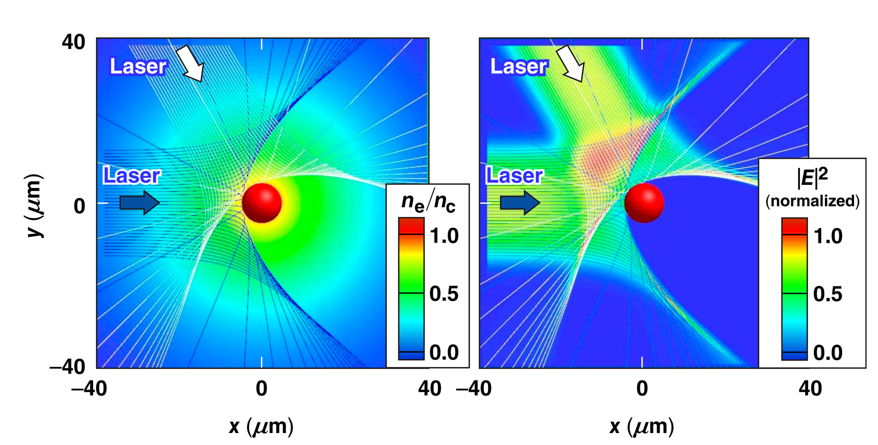

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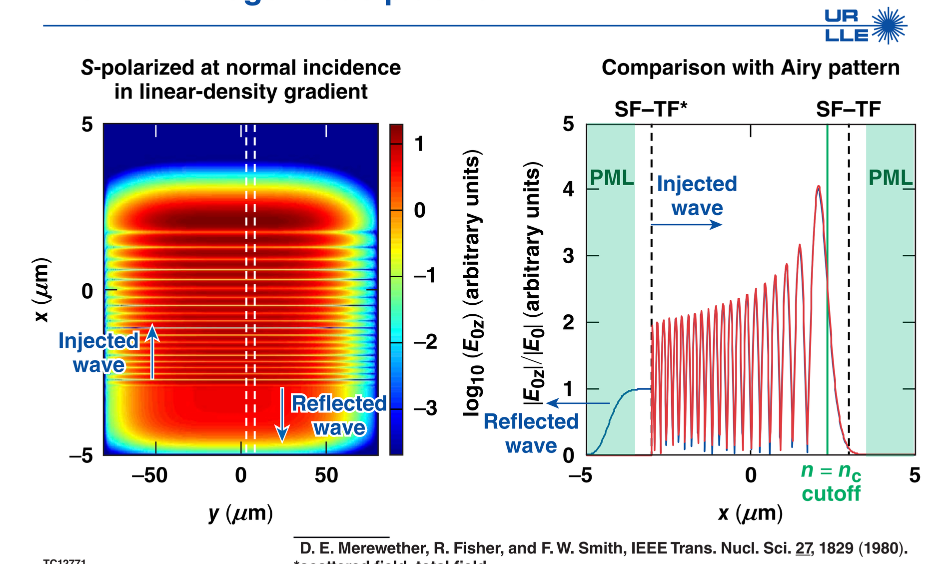

TC12771

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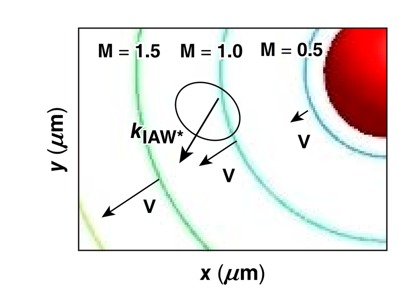

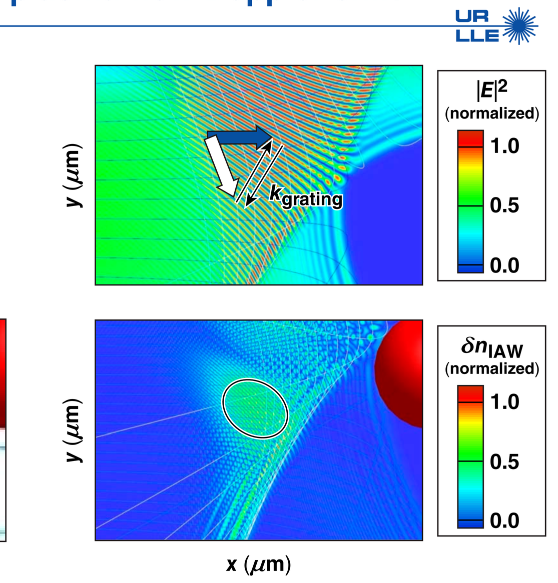

TC12774

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- Unlike x-ray drive, the presence of supersonic plasma flow enables the process to be resonant*
- Three-wave SBS equations are computed (pairwise) for each beam crossing using a generalization of Randall *et al.*,* and are implemented in-line in 1-D *LILAC*

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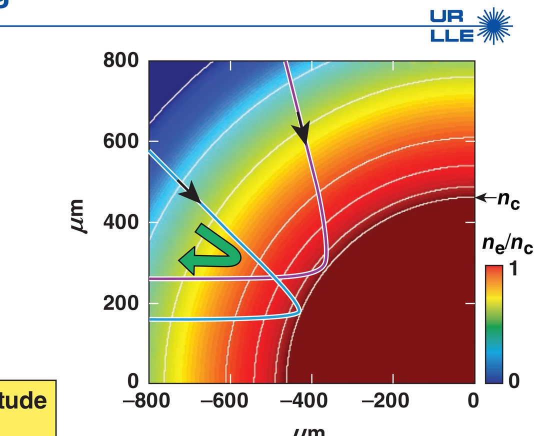

E17994e

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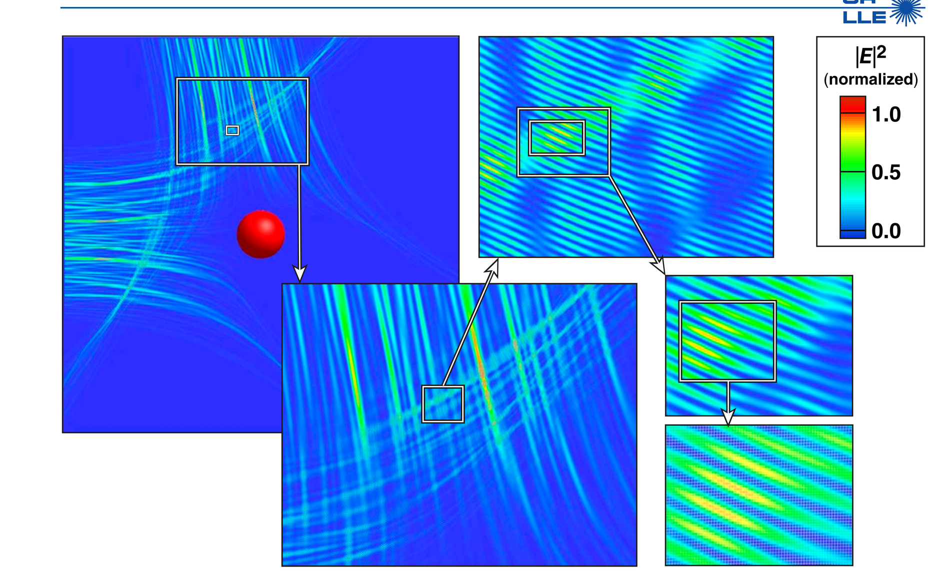

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TC12778

Wave-based models face several challenges and complications, but these can be overcome

- We are computing the motion of a semi-classical object by solving the (vector) Schrödinger equation
- Several key technical challenges were solved
  - time-enveloped (vector) wave equation in 3-D in strongly inhomogeneous plasma of a useful size
  - efficient algorithm is required (i.e., not Crank–Nicholson)
  - very complicated boundary conditions (in 3-D)
  - coupled to a plasma model
  - parallel efficiency [scalable solver for O(10^9) computational cells]
- The resulting wave solver is practical to run in 3-D
  - 100 Intel cores, could scale to 1000's
  - pioneering use/visualization of large datasets/fast disks at LLE [O(100 GB) sets]

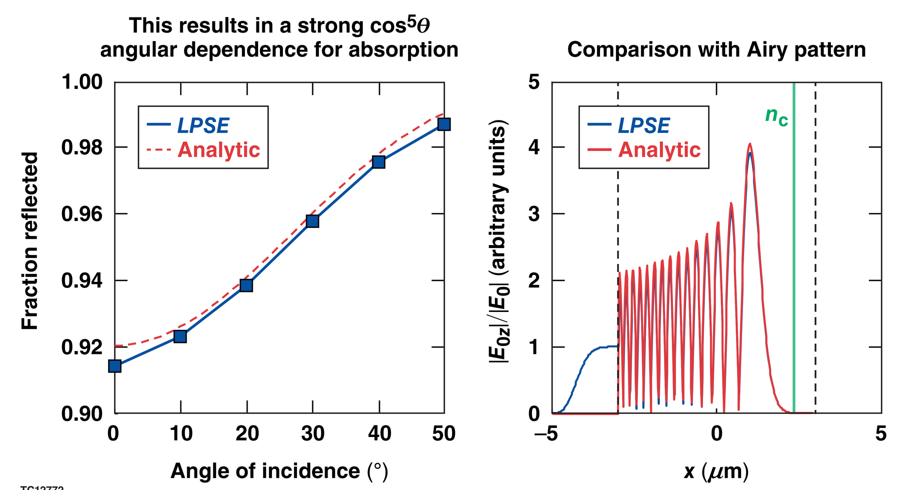
TC12769

Obliquely incident light turns at a lower density (shifted by $\cos^2\theta$ in a linearly varying density profile)

$$\left|\frac{E_y}{E_0}\right| \approx 2\sqrt{\pi}\left(\frac{\omega_0 L}{c}\right)^{1/6} A_i(\eta) \qquad \eta \equiv \left(\frac{\omega_0^2 L}{c^2}\right)^{1/3}\left(x - L + L\sin^2\theta\right)$$

This results in a strong $\cos^5\theta$ angular dependence for absorption

Comparison with Airy pattern



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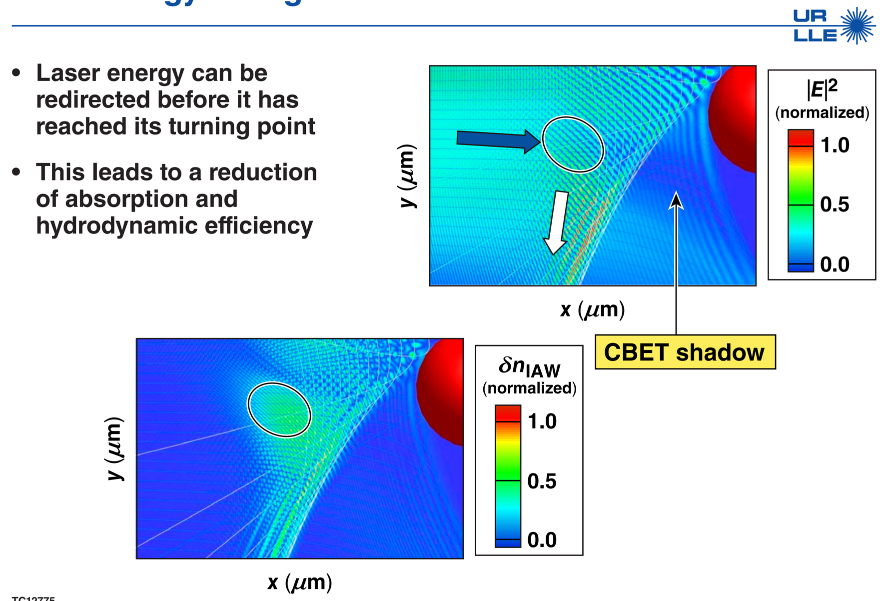

TC12775

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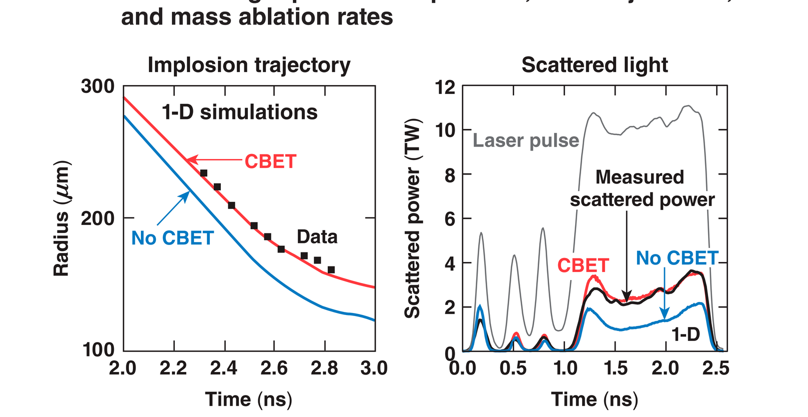

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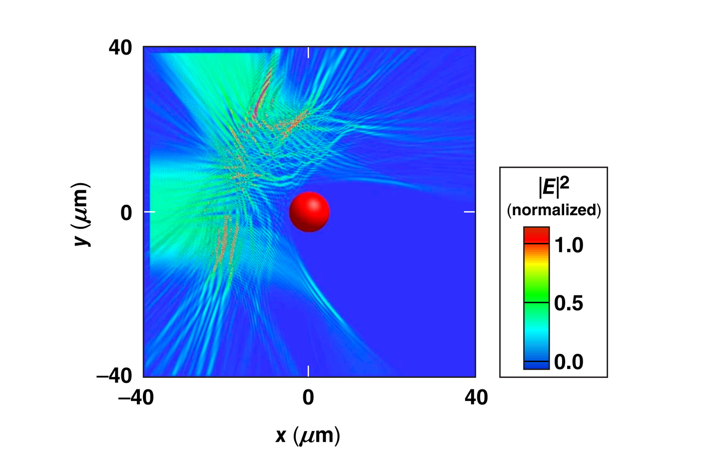

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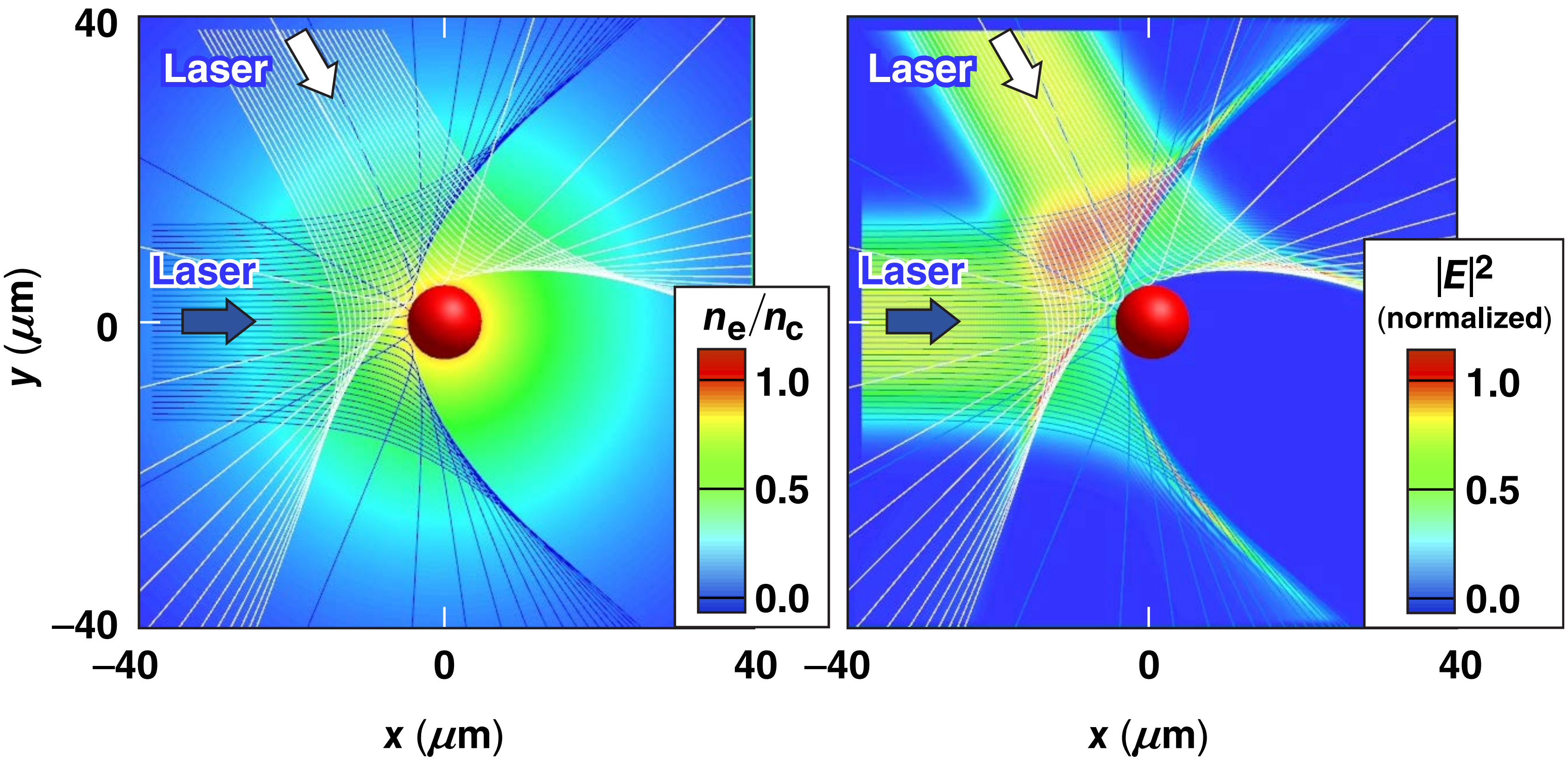

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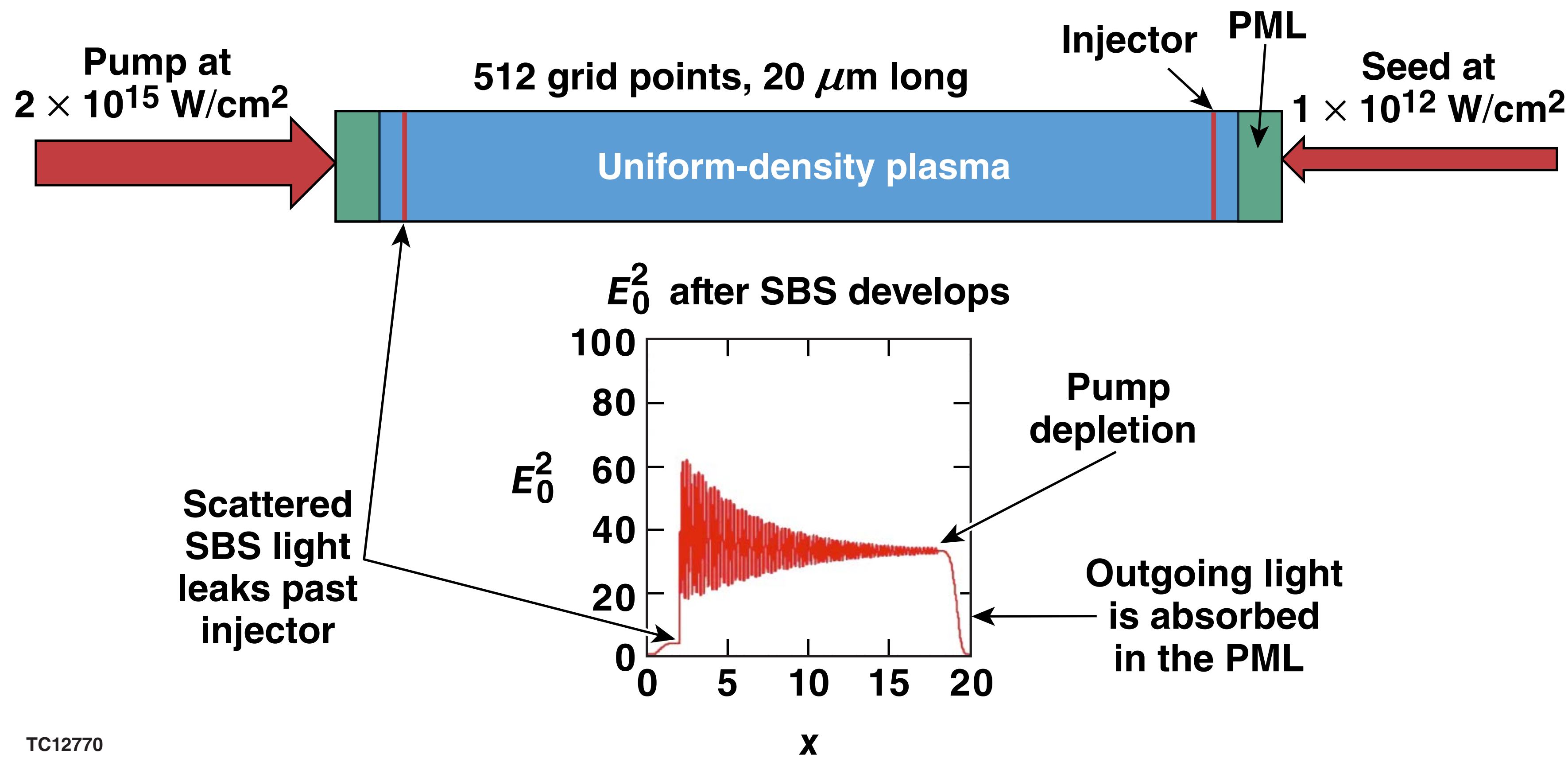

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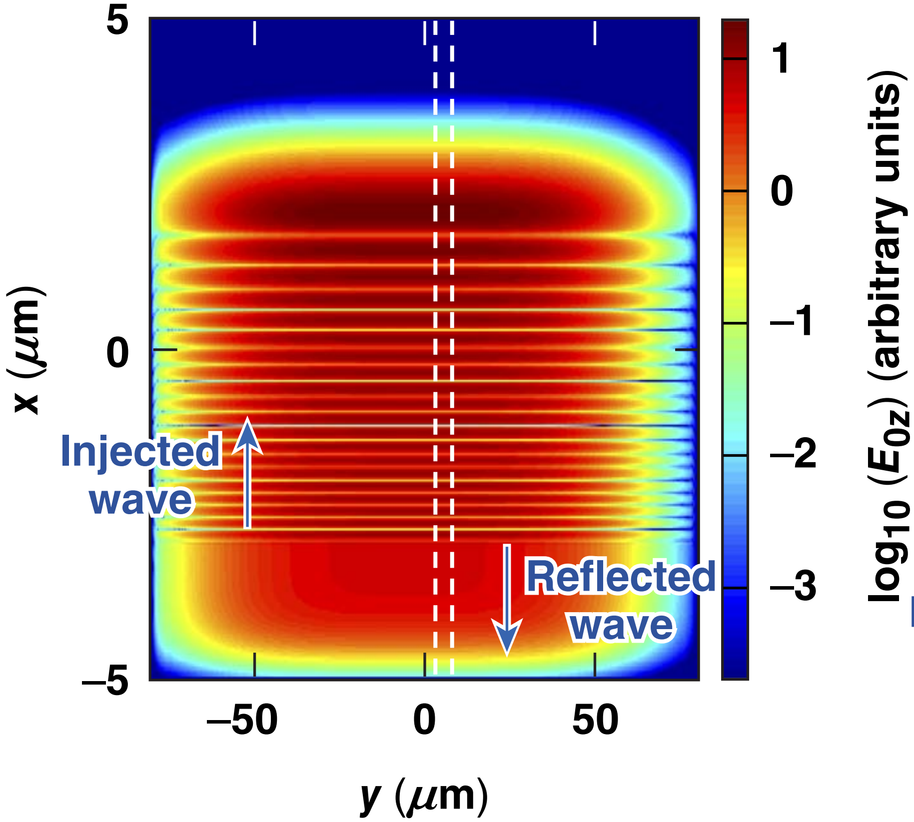
S-polarized at normal incidence in linear-density gradient



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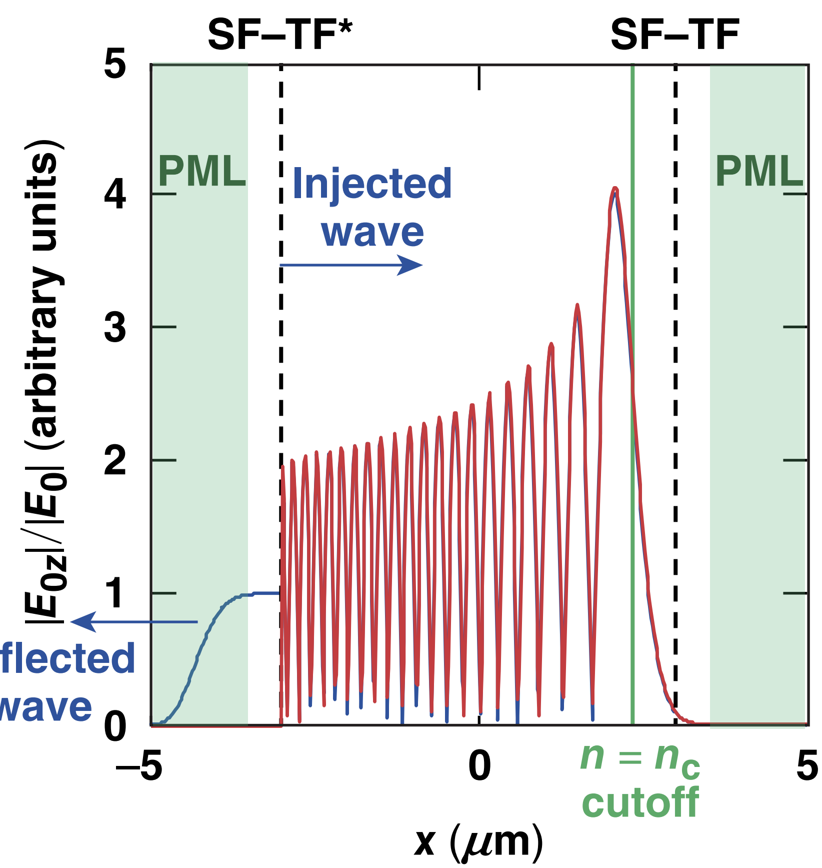

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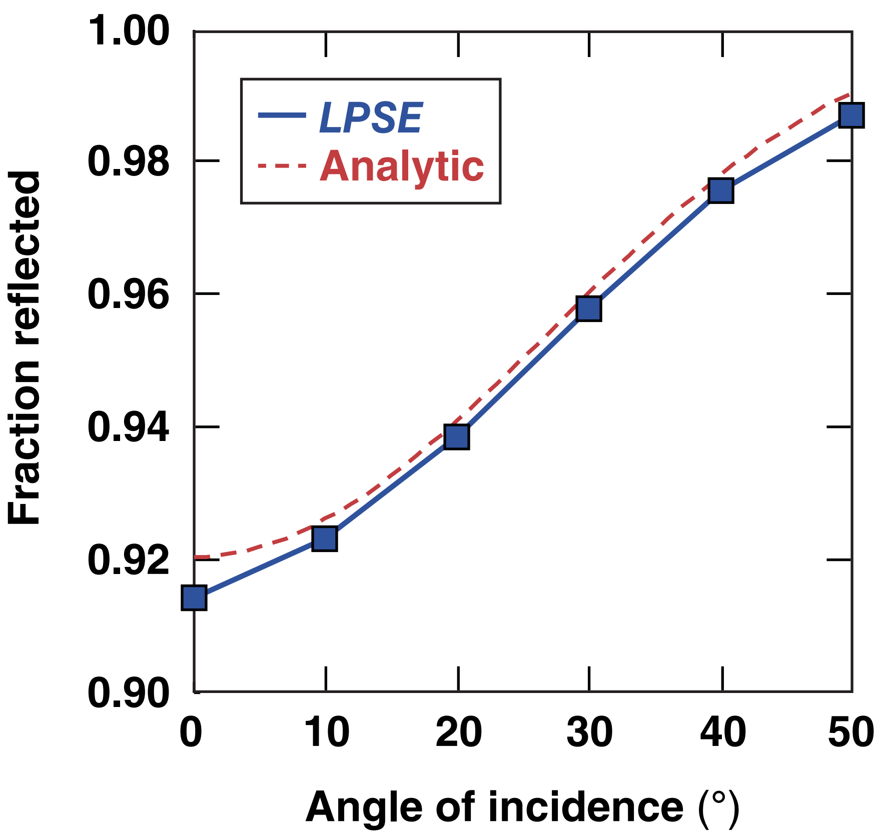

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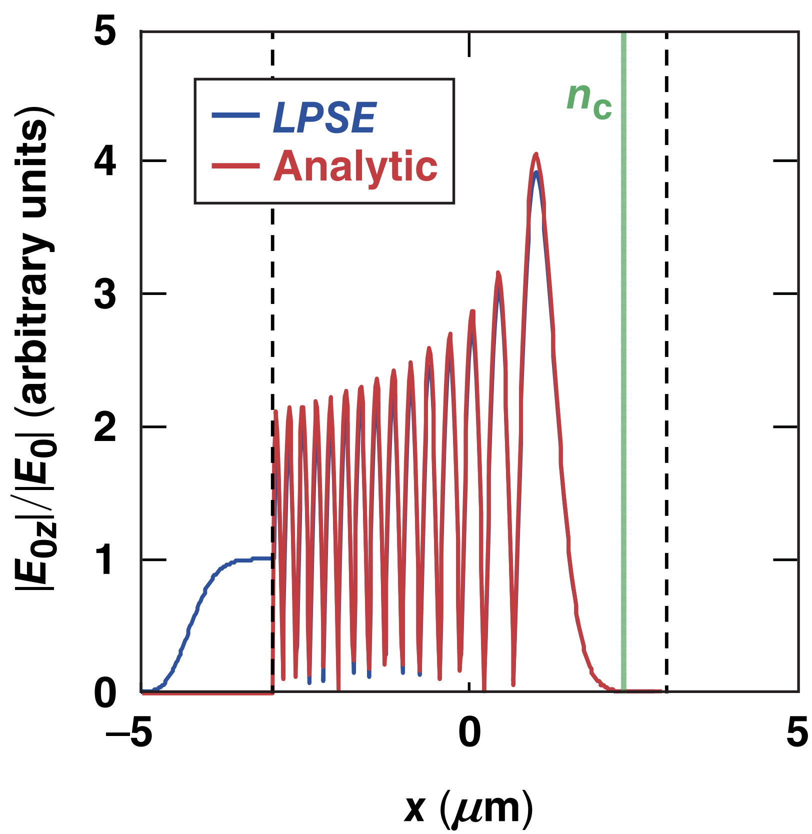

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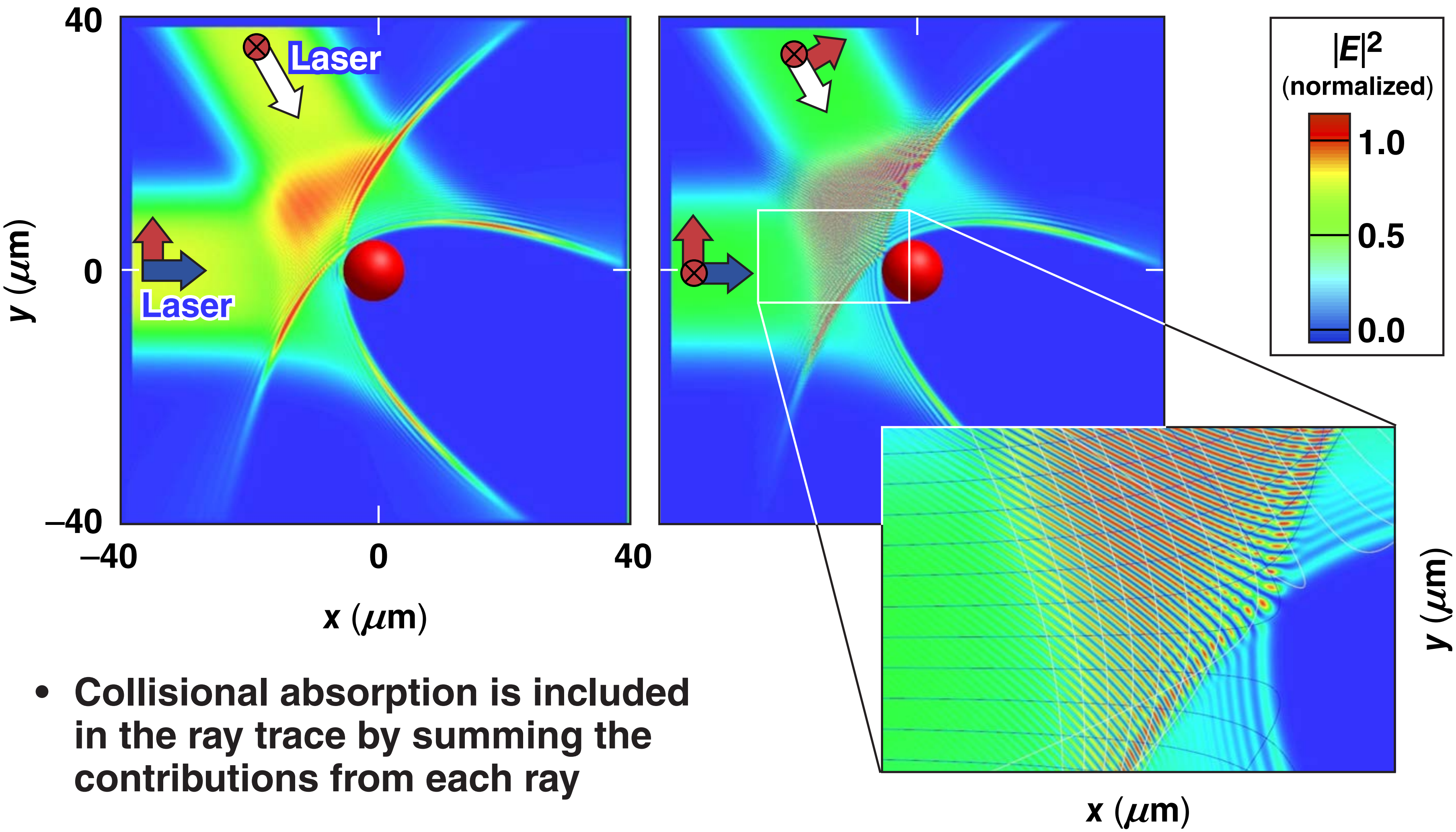

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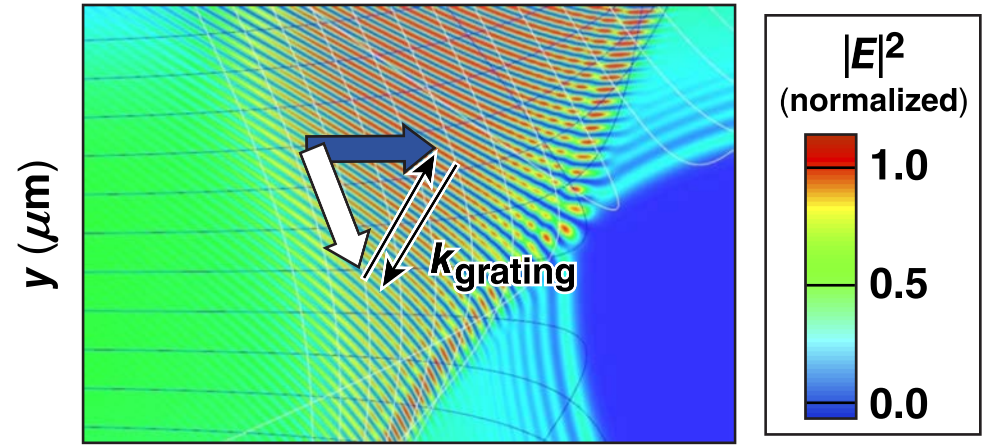

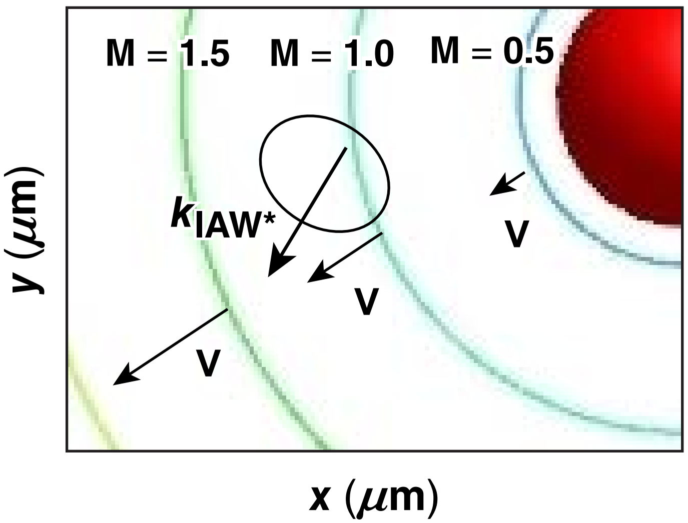

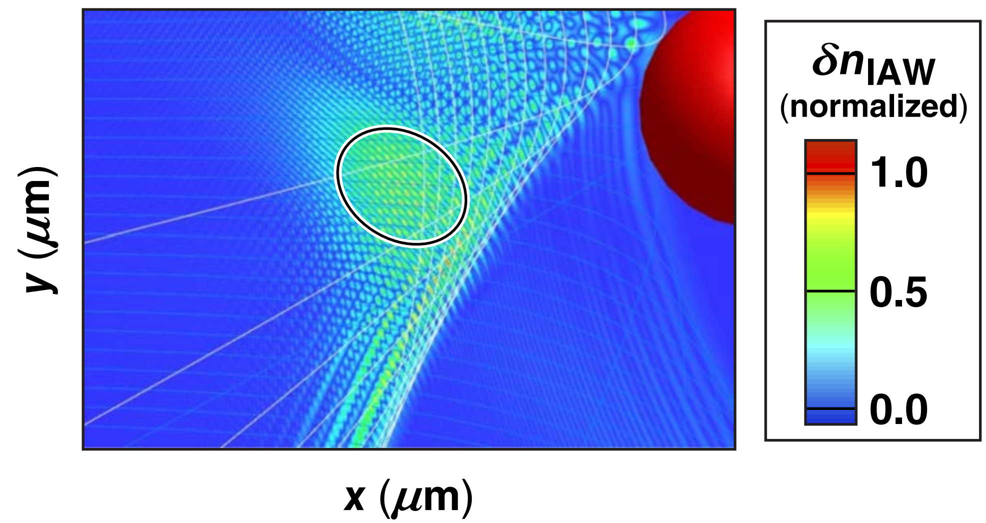

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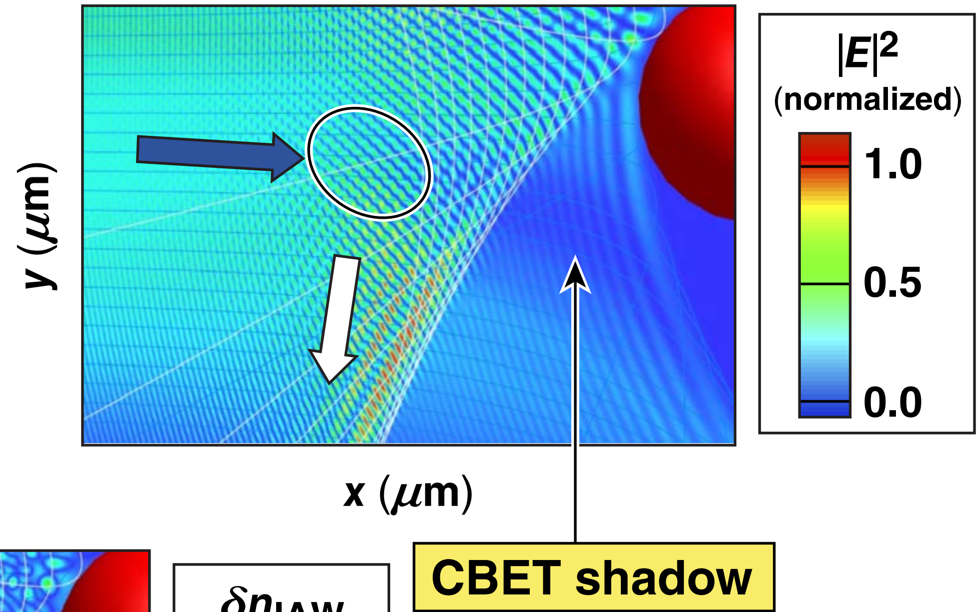

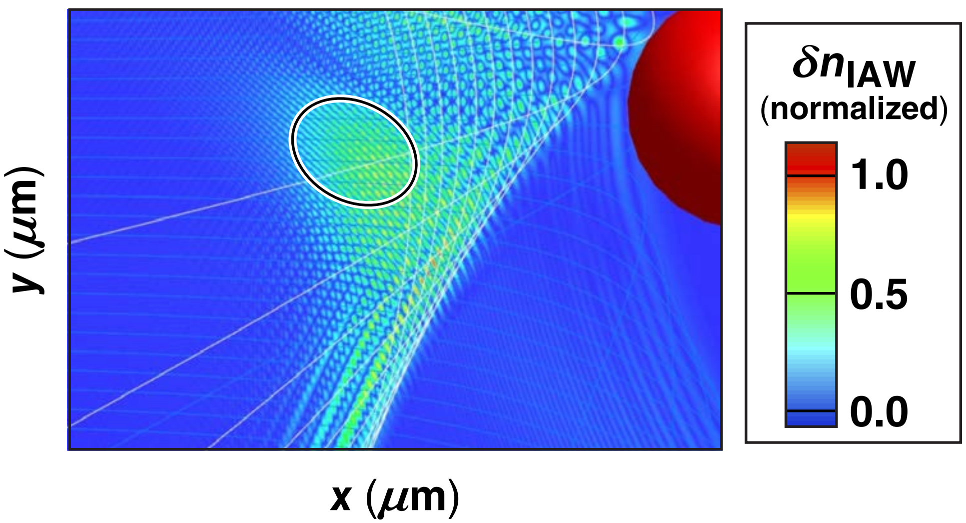

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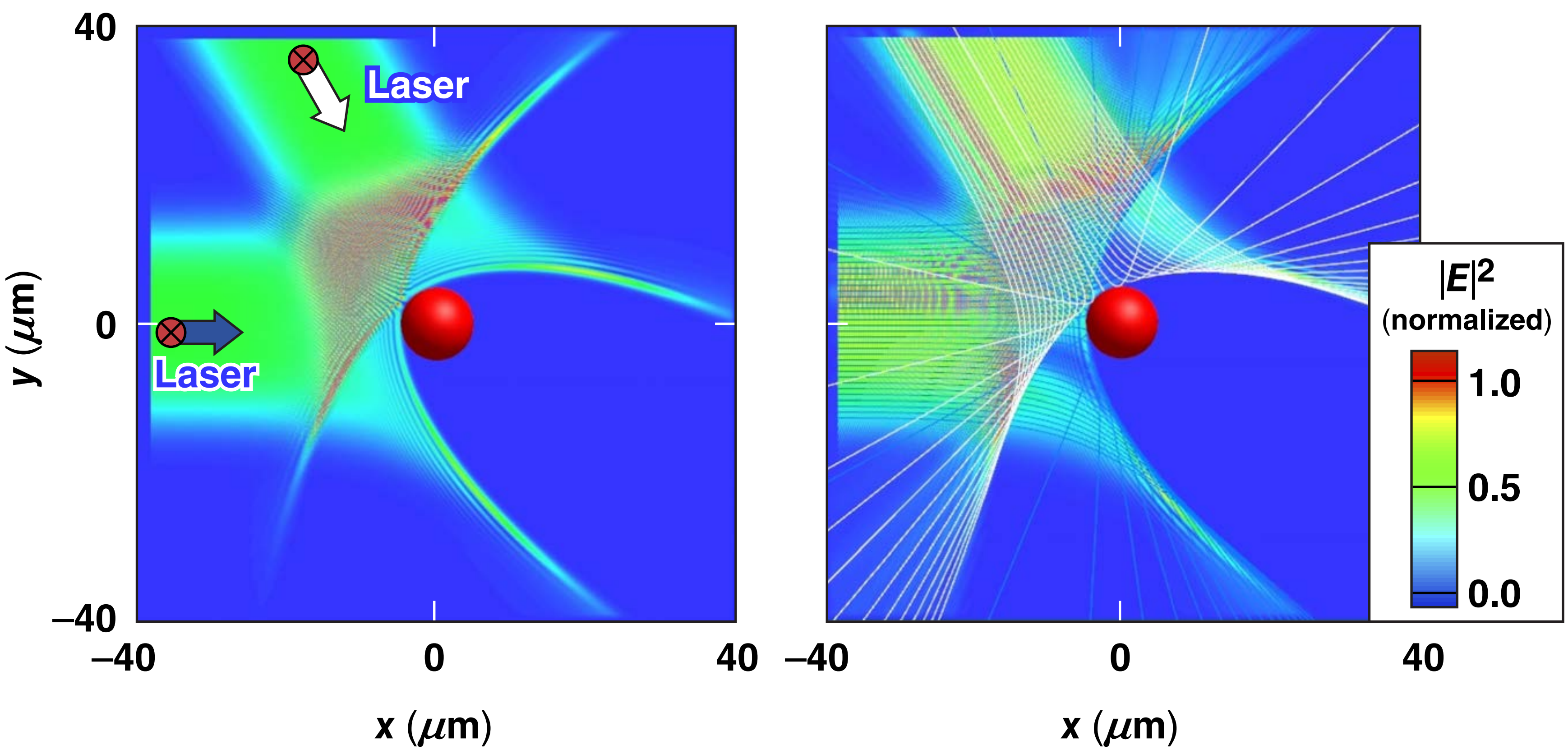

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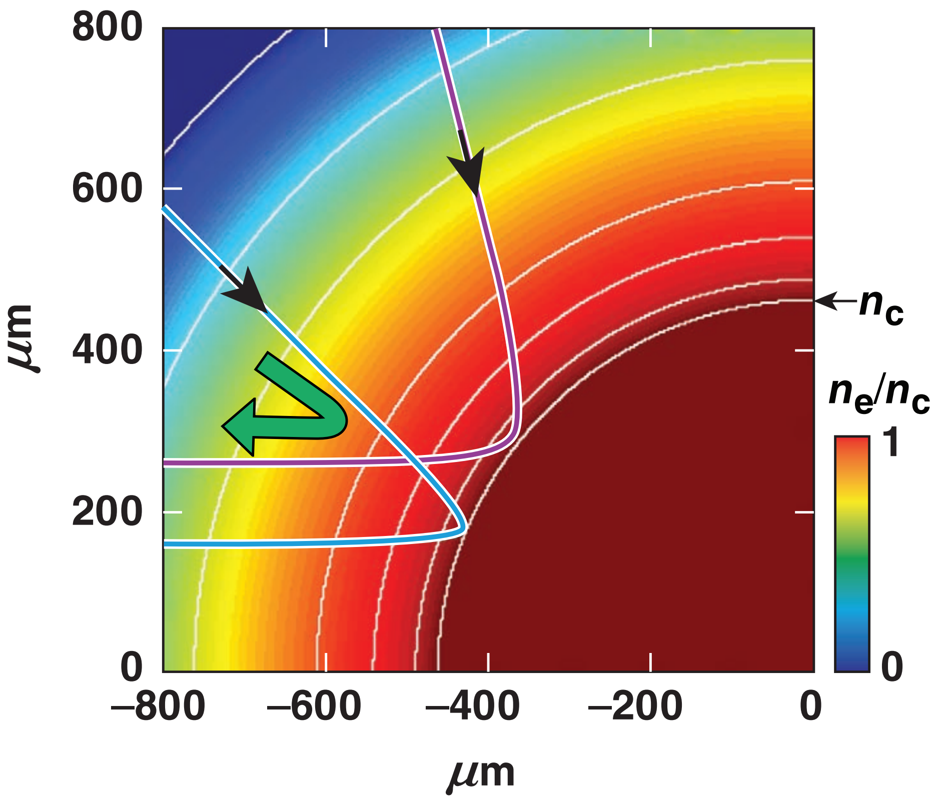

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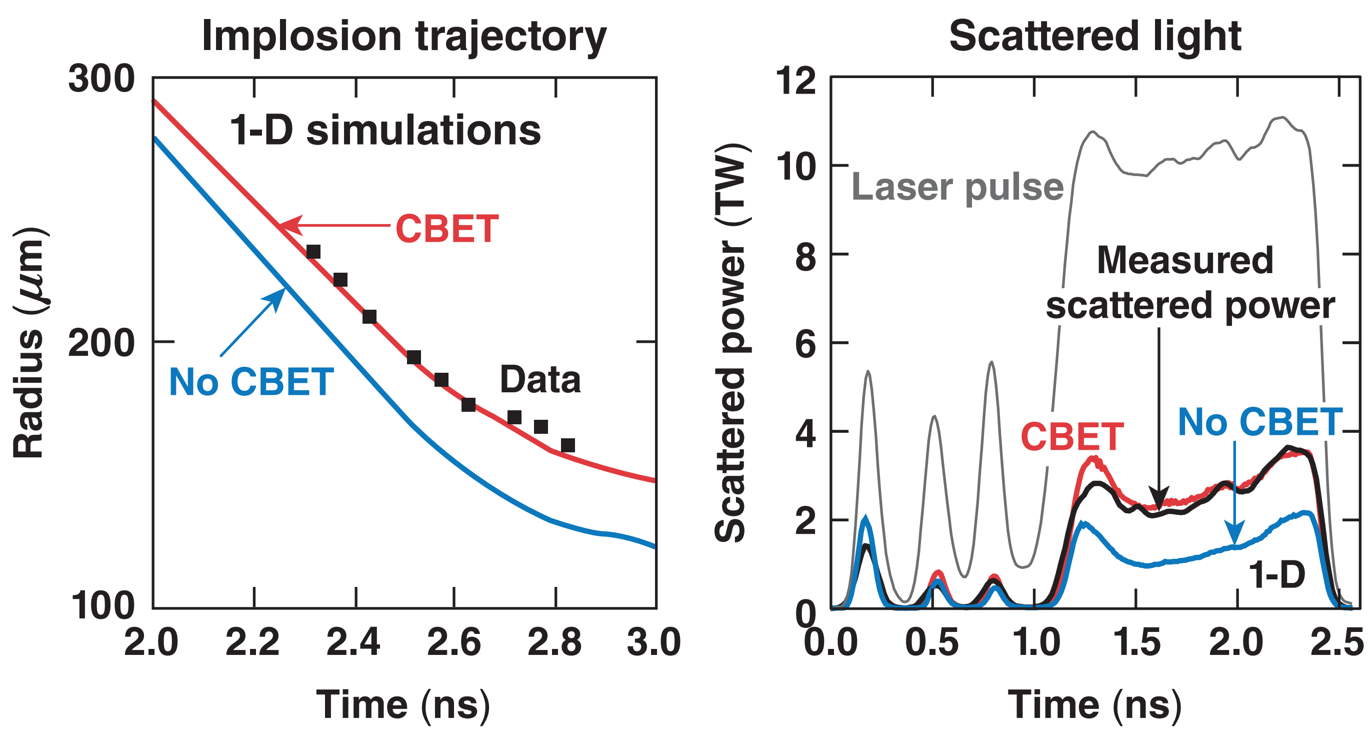

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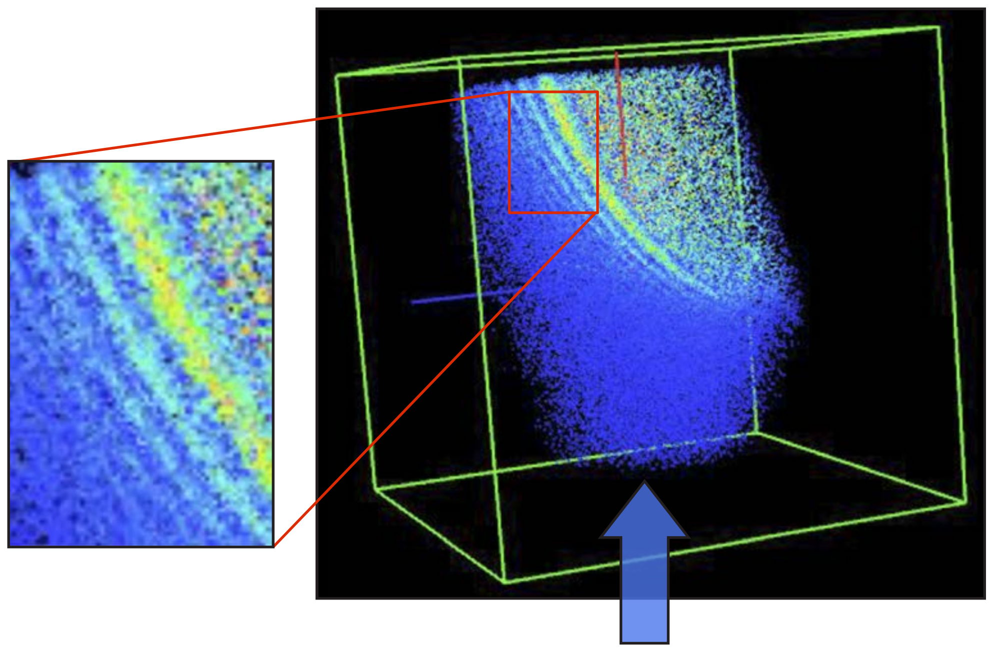

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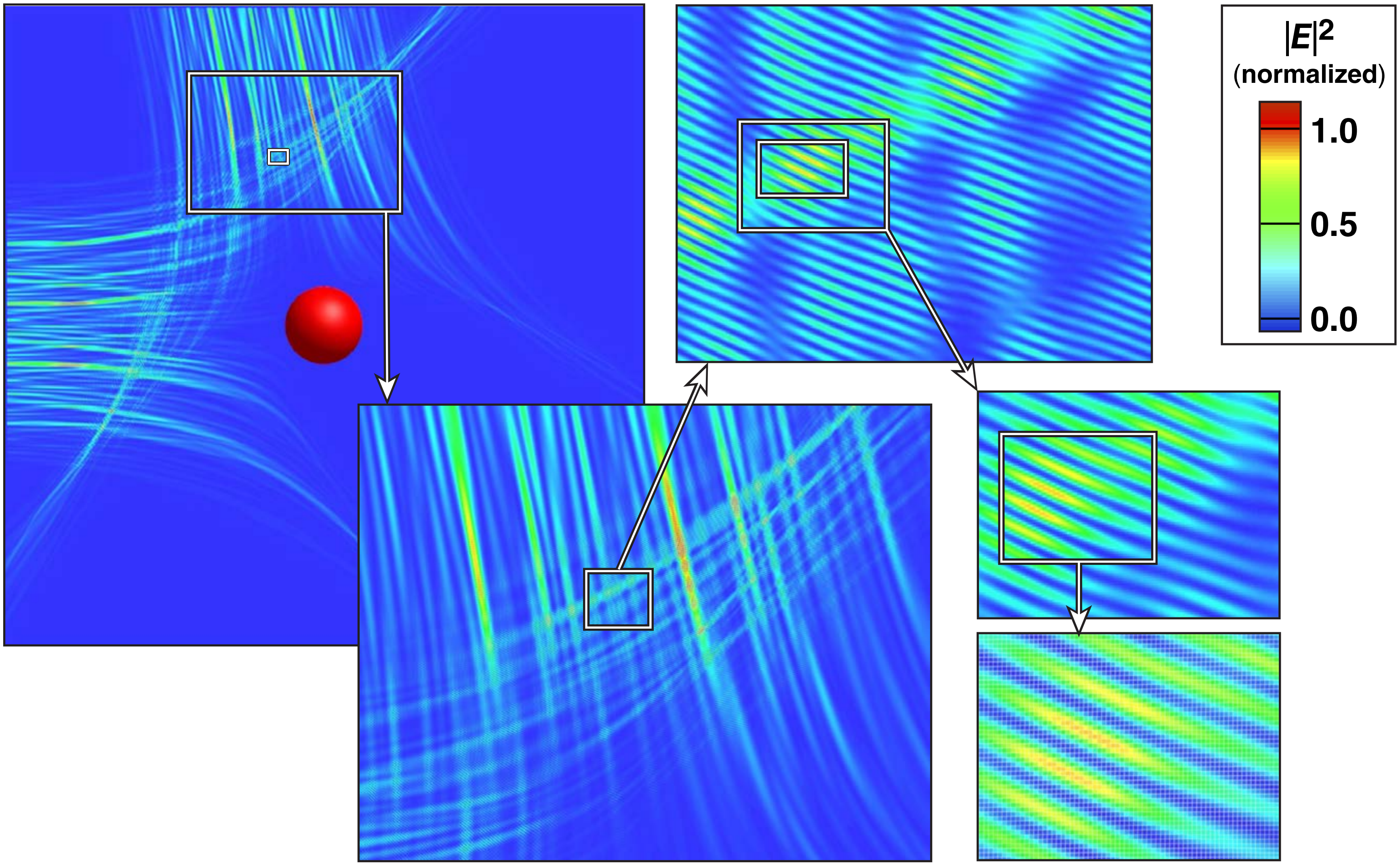

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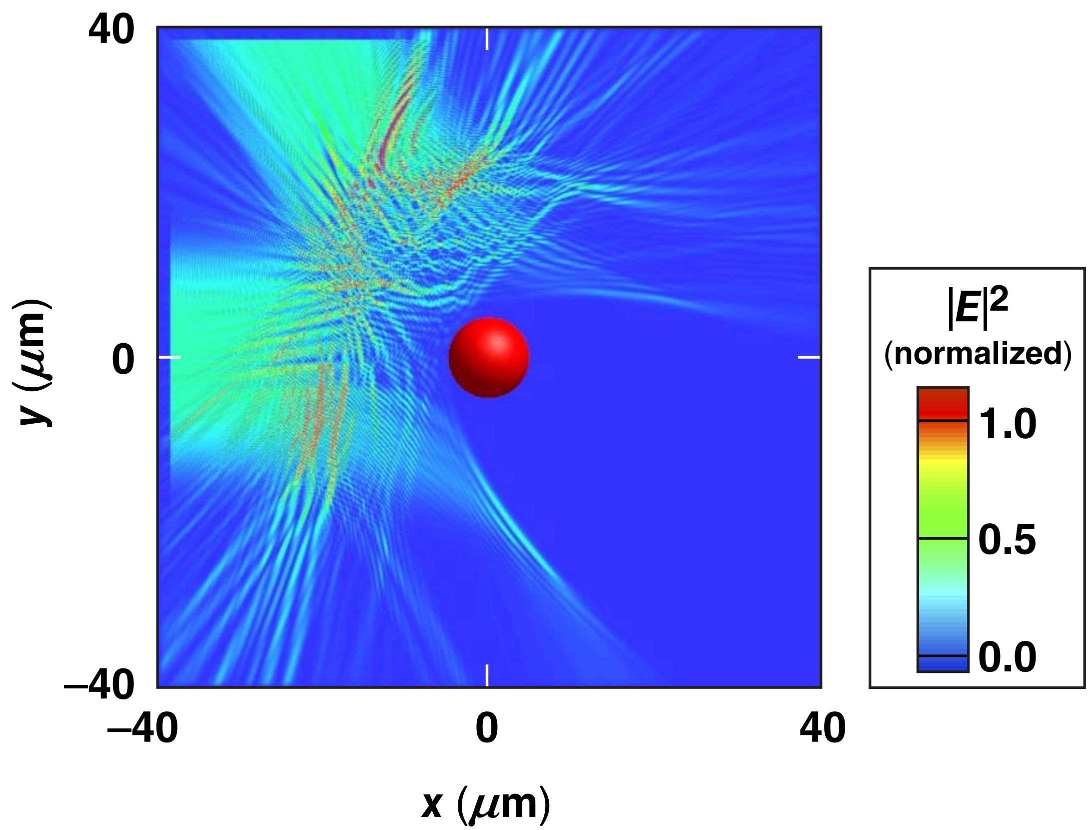

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