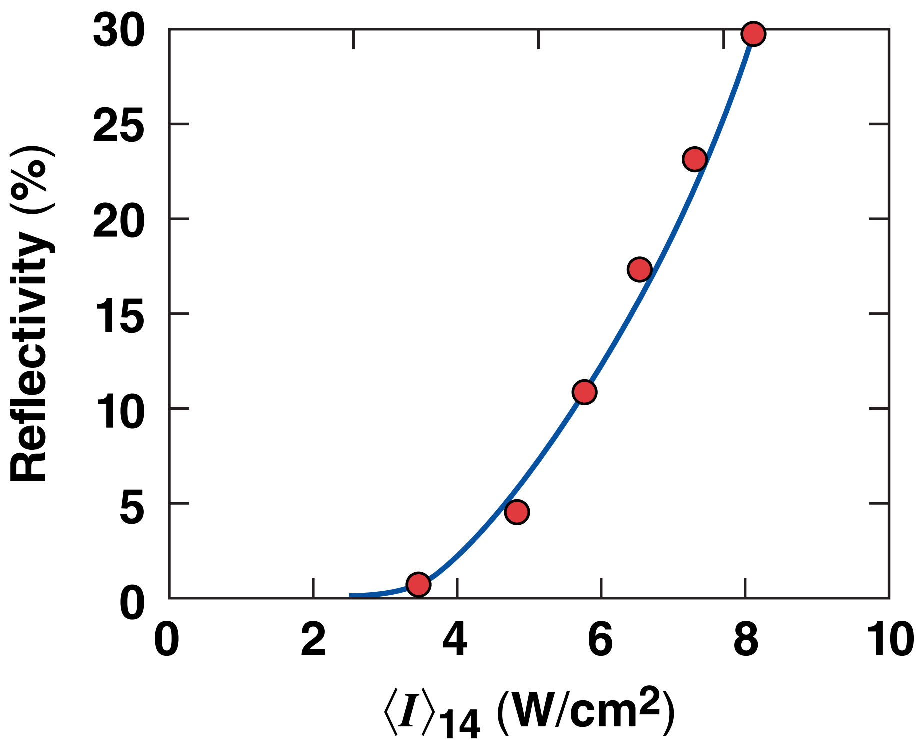
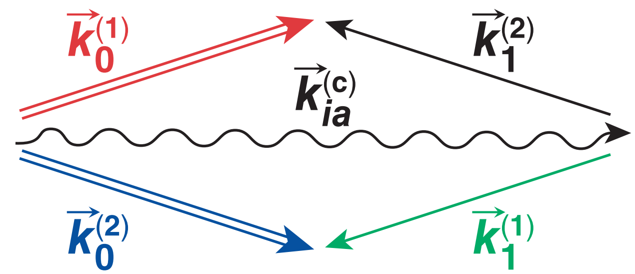
Interaction of Multiple Laser Beams via Common Waves and Beam-Energy Transfer





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Summary

For direct-drive ICF plasmas, scattering of light is driven by crossing laser beams that can generate common ion waves

- The reflectivity is determined by the interaction between incident crossing beams and the counter-propagating seed
- The reflectivity is increased in the case when multiple crossing beams drive common ion waves and scatter off them
- The direction of scattered light is determined by the laser speckle structure
- The scaling of reflectivity with intensity is determined by the interaction in high-intensity speckles

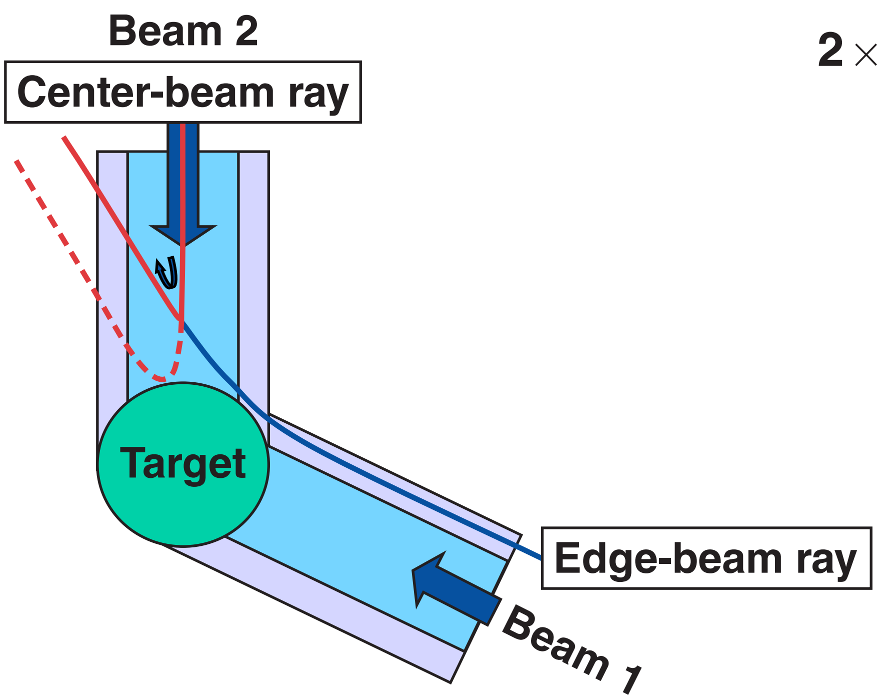
Outline

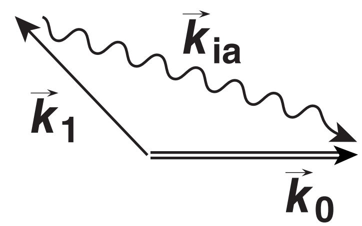
1. Numerical modeling of nonlinear interaction between crossing laser beams
2. Common ion-acoustic waves driven by multiple laser beams
3. Scaling of reflectivity with laser intensity
4. Interaction between multiple laser beams incident at different angles

In large-scale hydrodynamic simulations, cross-beam energy transfer is shown* to significantly influence the laser absorption

- For direct-drive ICF plasmas, the interaction between rays is

$$\frac{dI_1}{d\ell} = I_1 I_0 \underbrace{\frac{\omega_0^2}{2c^2 n_c} \mathrm{Re}\left\{ \frac{n_e k_{ia}^2 c_{ia}^2}{2\nu_i \omega_{ia} + i\left[(\omega_{ia} + k_{ia} v_0)^2 - k_{ia}^2 c_{ia}^2\right]} \times \frac{1}{2k_{0x}} \right\}}_{2 \times \mathrm{Re}\, g(\vec{k}_{ia})}$$





- Cross-beam energy transfer reduces the energy of incoming center-beam light and increases the energy of outgoing edge-beam light

E19905h

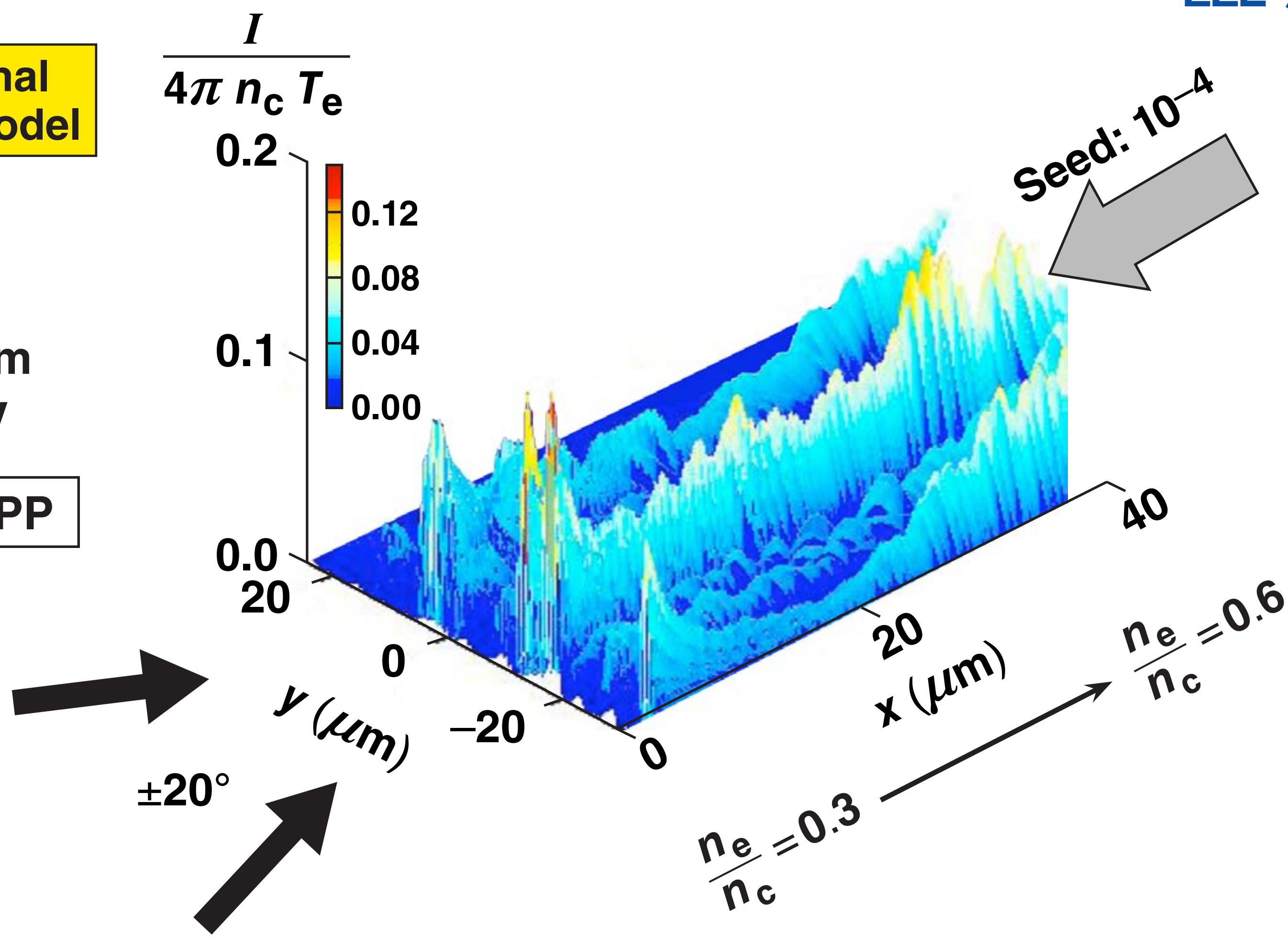
*I. V. Igumenshchev *et al.*, Phys. Plasmas 19, 056314(2012).

The nonlinear propagation of crossing laser beams has been modeled in the region of moderate plasma density, about 0.3 n_c to 0.6 n_c

Two-dimensional nonparaxial model

L_n = 140 μm
T_e = 2 keV

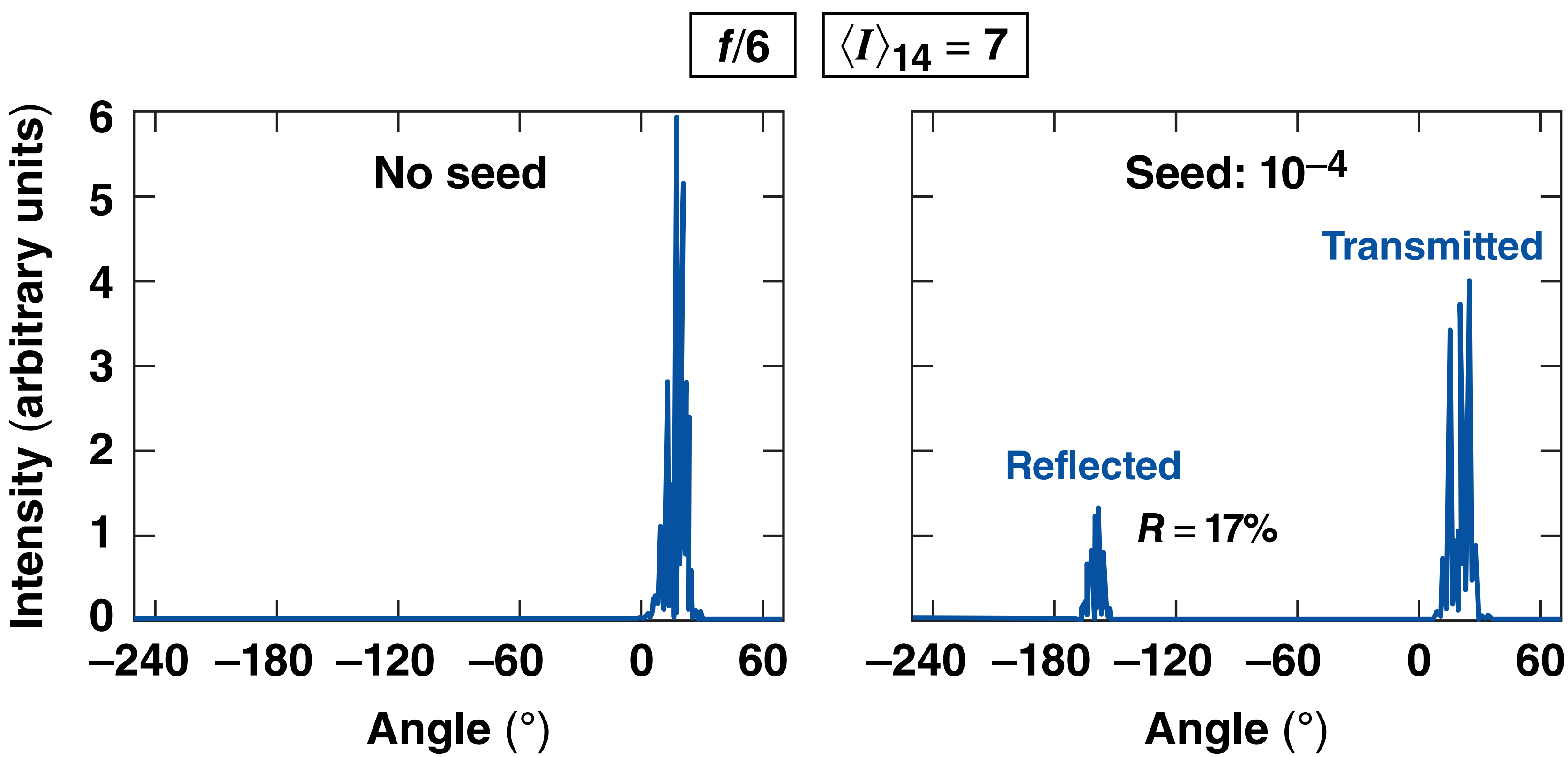
f/6 or *f*/15 DPP



TC9444a

The backscatter depends on the electromagnetic seed, which is caused by opposing beams or turning beams

Scattering from a single DPP beam*

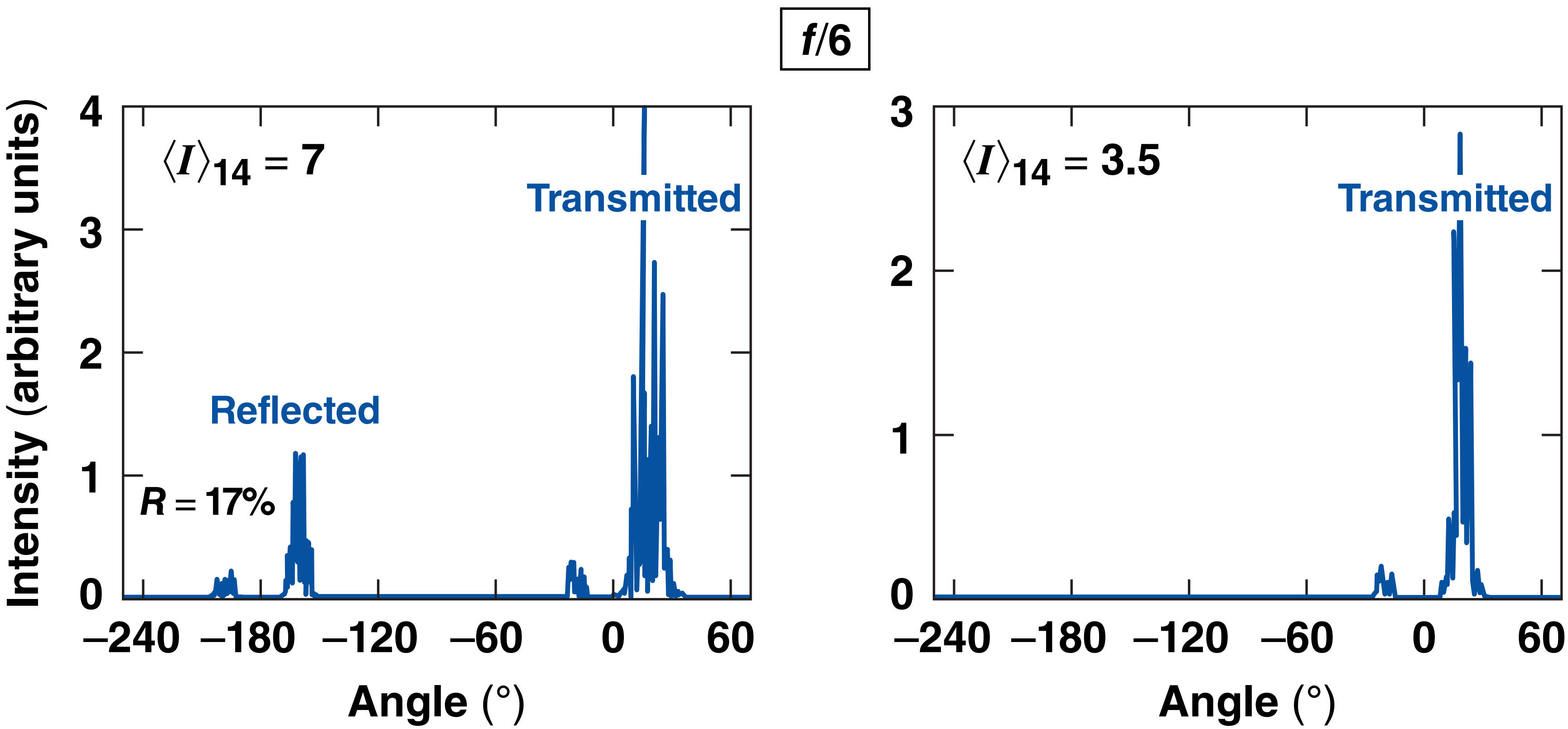


TC9501a

*H. A. Rose and D. F. DuBois, Phys. Rev. Lett. 72, 2883 (1994).

The threshold for the backscattering driven by crossing laser beams has been found at moderate laser intensities

- The intensities of the two driving beams are different by a factor of 10

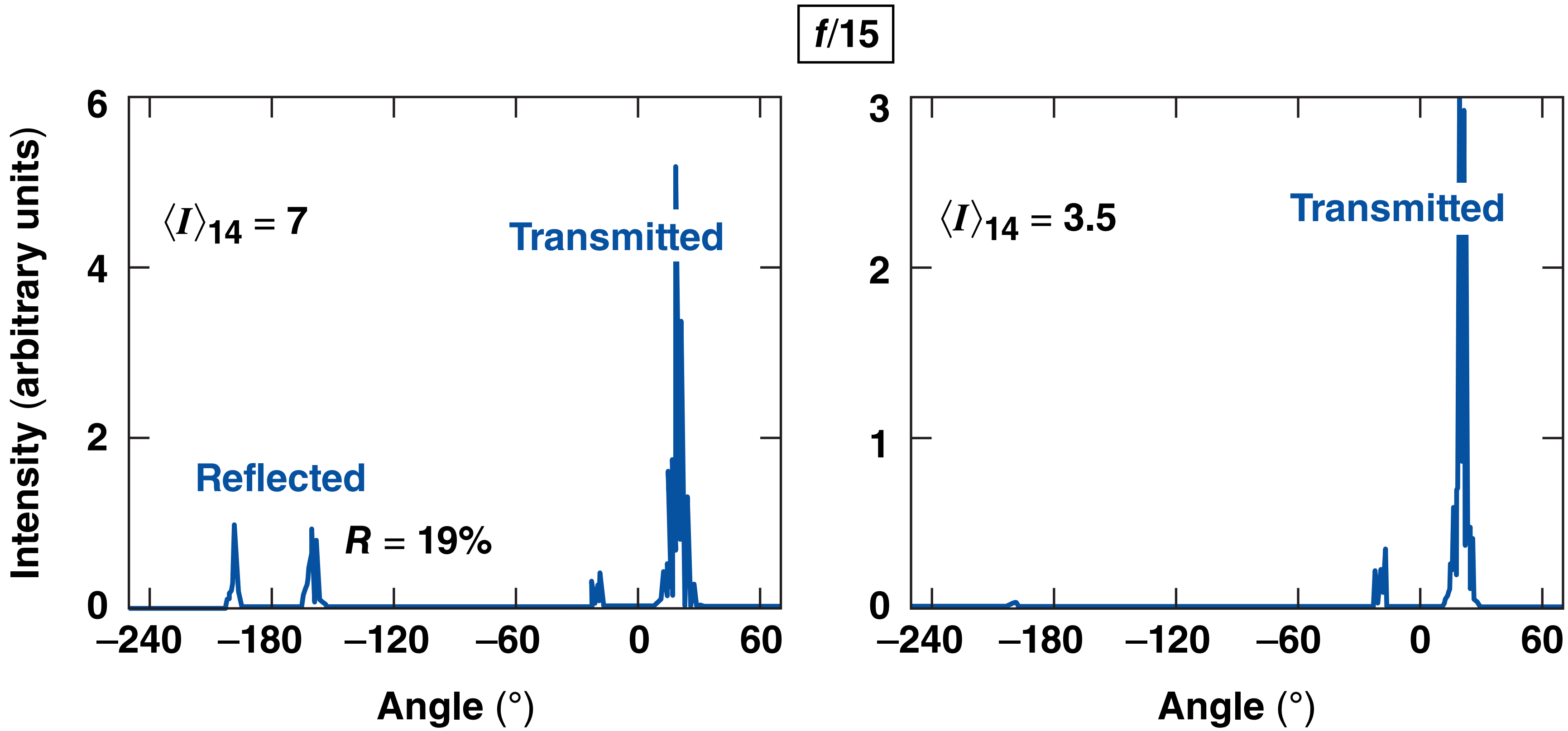


$$G_{SBS} = 0.24 \langle I \rangle_{14} \left(\frac{I_{max}}{\langle I \rangle} \right)$$

Interaction in intense hot spots

TC9445a

In the case of incident beams of unequal intensity with smaller angular width, the backscattering for both beams is of the same order

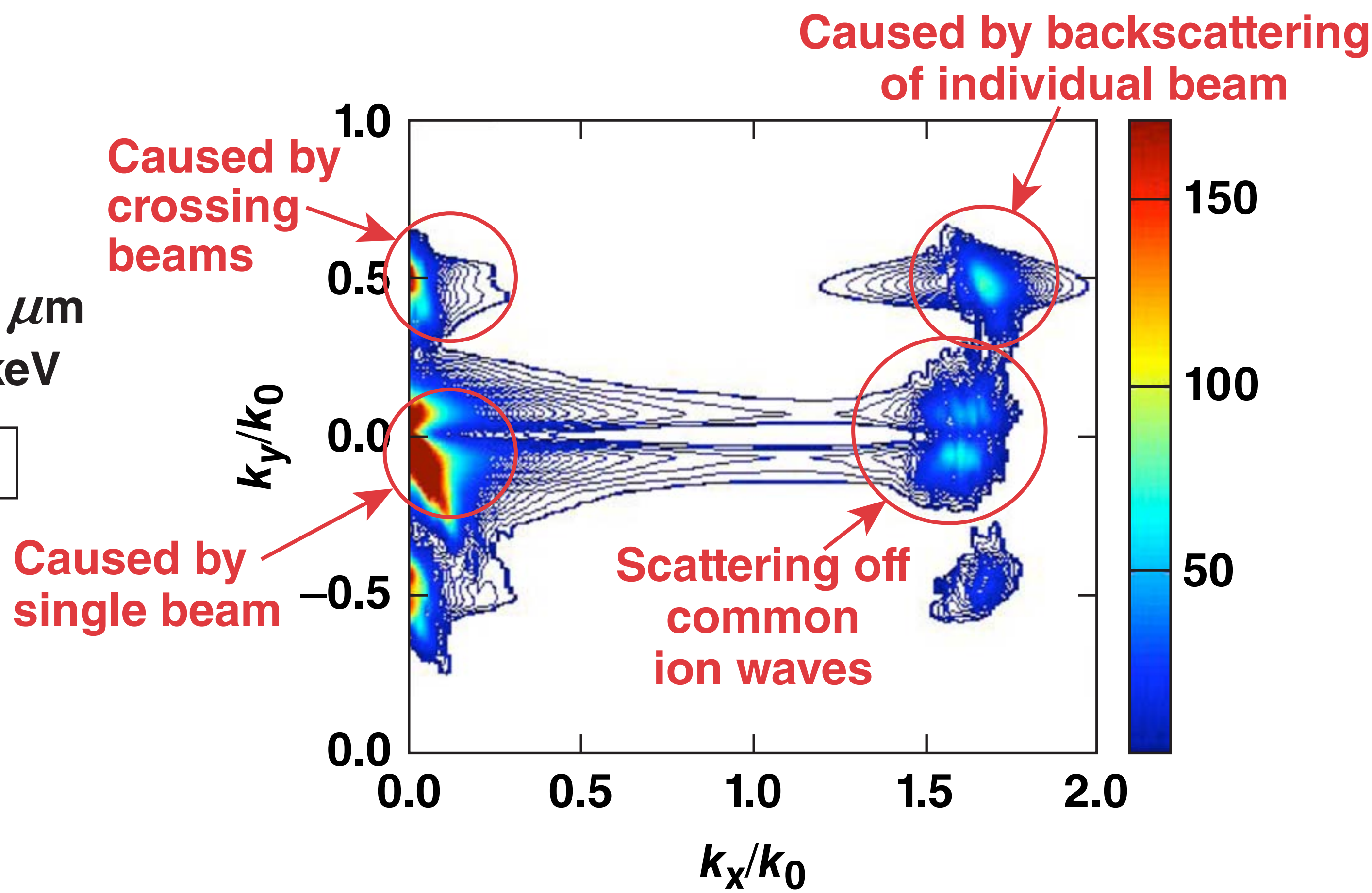


TC10059

The interaction of incoherent crossing laser beams with plasmas produces a broad spectrum of low-frequency density perturbations

$L_n = 140\ \mu m$
$T_e = 2$ keV

f/6

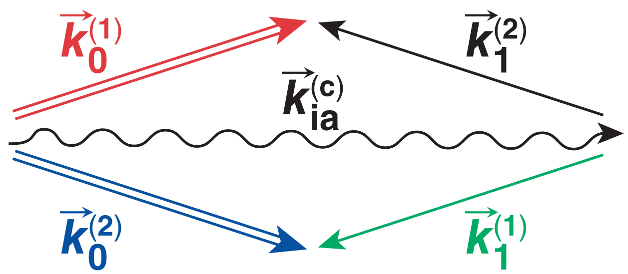


Laser beams can share density perturbations.

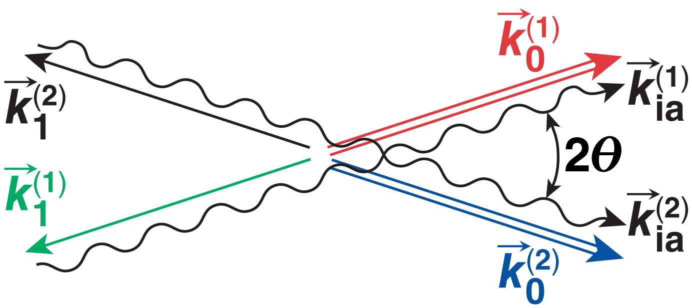
TC9448b

Crossing laser beams may scatter off common ion waves driven by multiple beam

Scattering off common ion waves



Backscattering of individual beams



$$\frac{dE_1^{(1)}}{d\ell_1} = g\left(\vec{k}_{ia}^{(c)}\right)\underbrace{\left(E_1^{(1)}E_0^{(2)*} + E_1^{(2)}E_0^{(1)*}\right)}E_0^{(2)} + g\left(\vec{k}_{ia}^{(1)}\right)\underbrace{\left|E_0^{(1)}\right|^2 E_1^{(1)}}$$

$$\frac{dE_1^{(2)}}{d\ell_2} = g\left(\vec{k}_{ia}^{(c)}\right)\underbrace{\left(E_1^{(1)}E_0^{(2)*} + E_1^{(2)}E_0^{(1)*}\right)}_{\text{common grating}}E_0^{(1)} + g\left(\vec{k}_{ia}^{(2)}\right)\underbrace{\left|E_0^{(2)}\right|^2 E_1^{(2)}}_{\text{backscattering}}$$

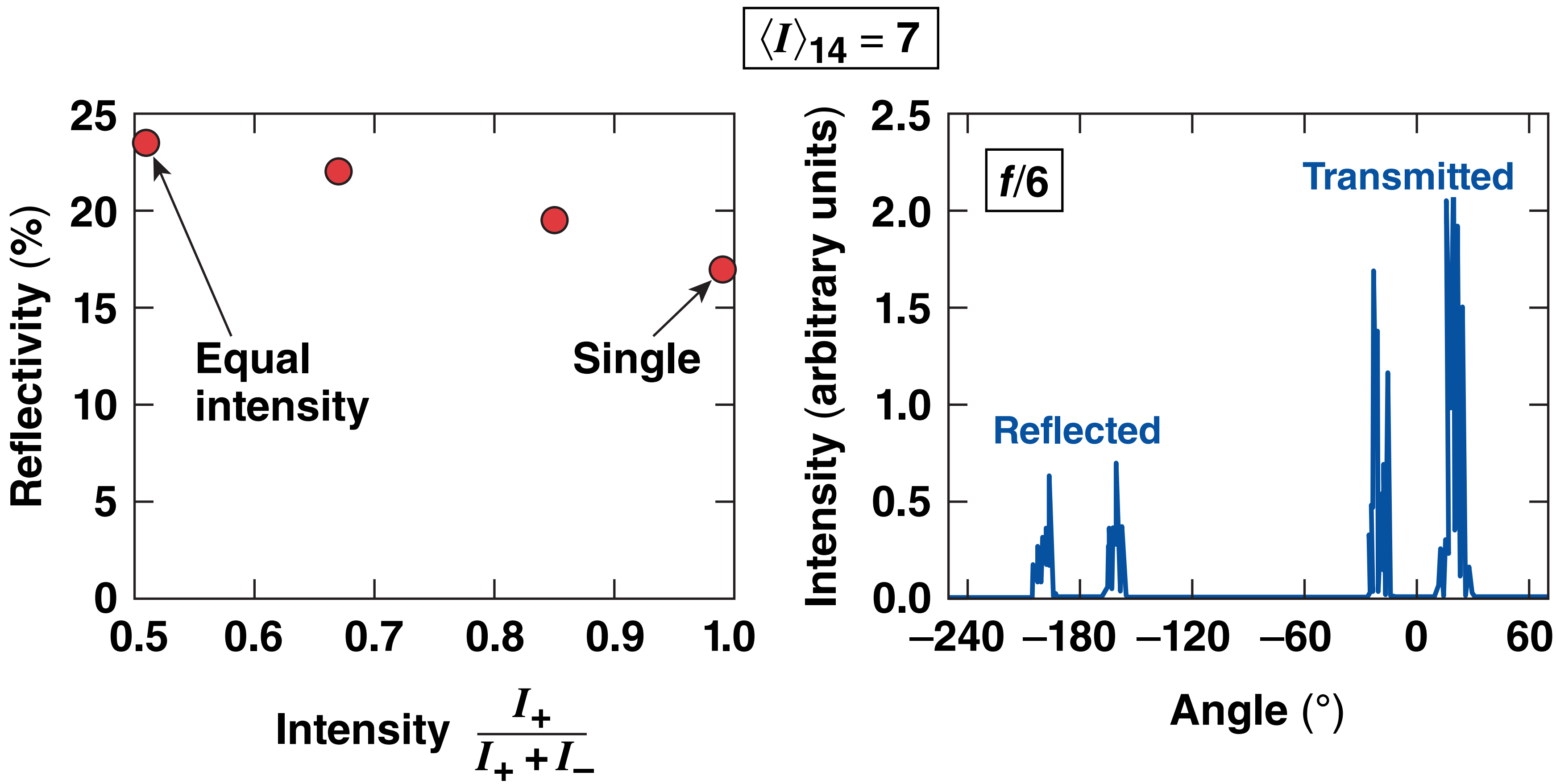
The difference in the resonance width in $g\left(\vec{k}_{ia}^{(c)}\right)$ versus $g\left(\vec{k}_{ia}^{(1)}\right)$ and $g\left(\vec{k}_{ia}^{(2)}\right)$ is ~$(\sin\theta)^2$ comparable to width caused by damping and inhomogeneity

Scattering is possible in the direction opposite to the weaker beam

TC10058

The reflectivity has a moderate dependence on the distribution of intensity between the driving laser beams

UR LLE



The hot-spot structure determines the direction of scattered light.

TC9798

The nonlinear interaction in intense laser speckles determines the scaling of reflectivity with intensity

Reflectivity

$$\frac{d\langle R\rangle}{dx} \sim U_m^3 e^{-U_m},$$

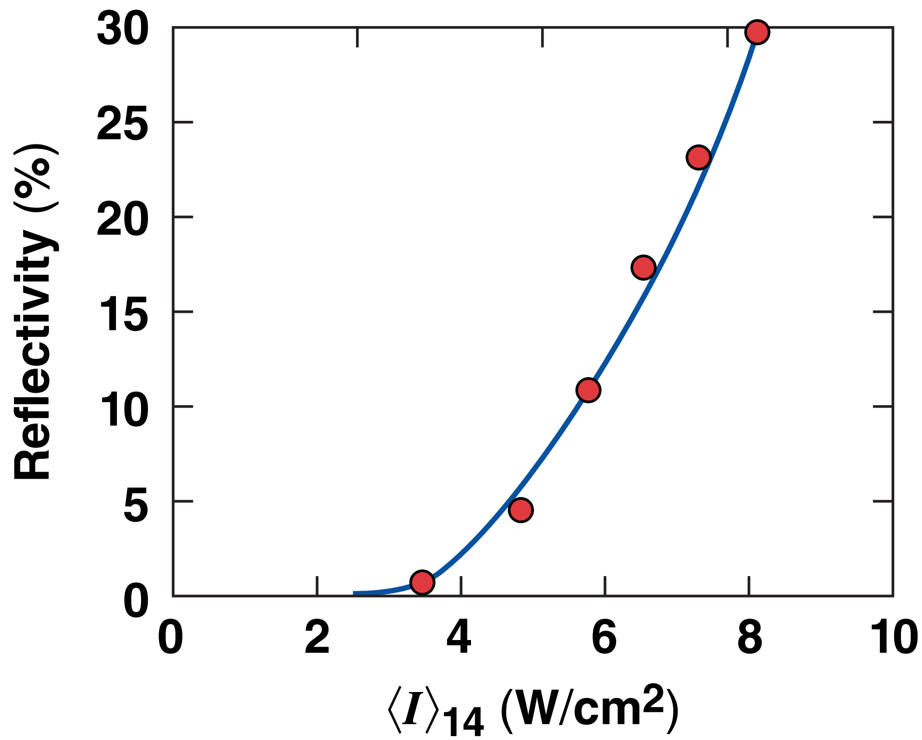
where

$$U_m \equiv \frac{I_m}{\langle I\rangle}$$

for the saturation R_{sat}

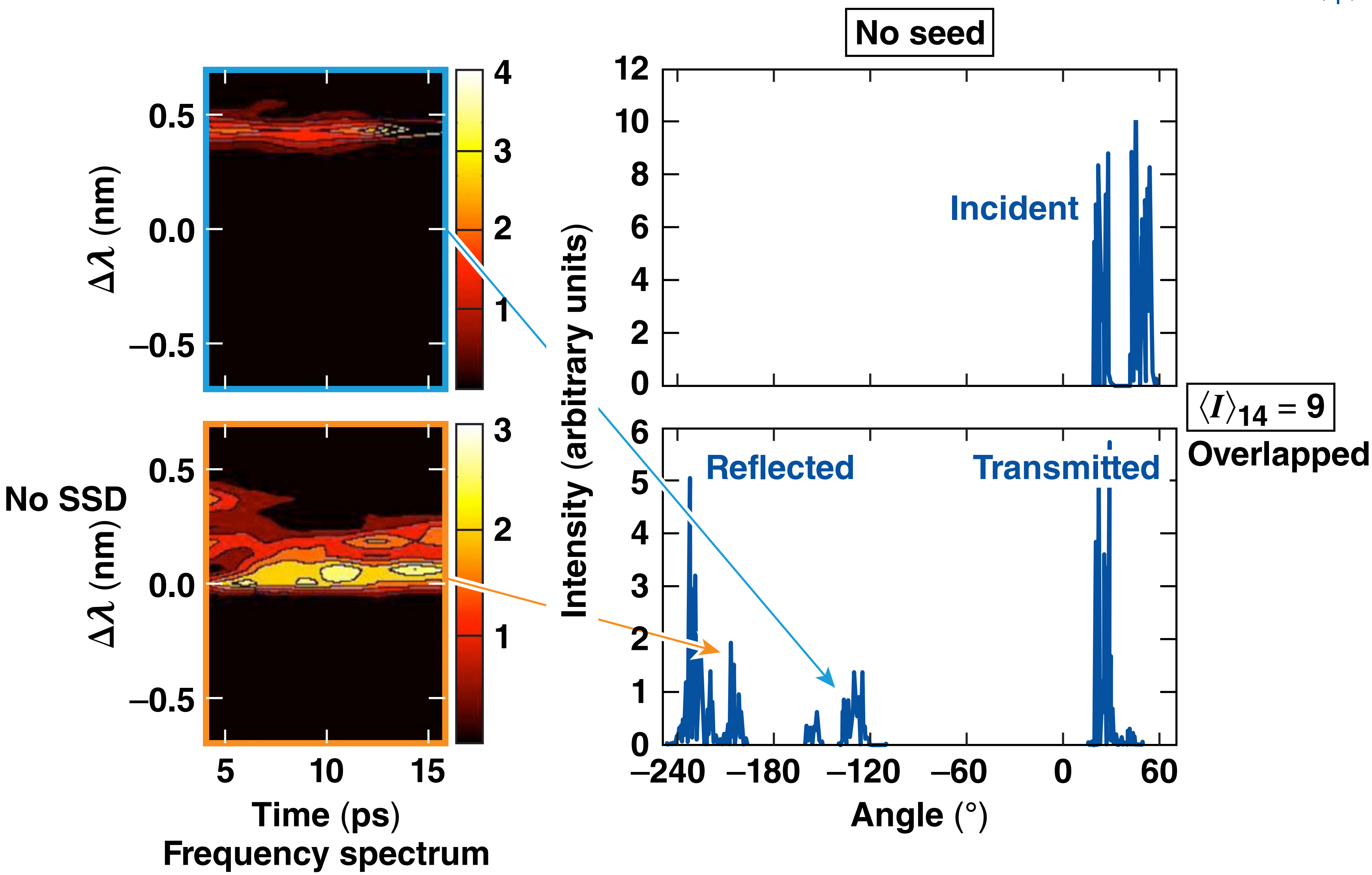
$$R_{sat} = \varepsilon\, e^{\langle G_{SBS}\rangle U_m}$$

ε – seed



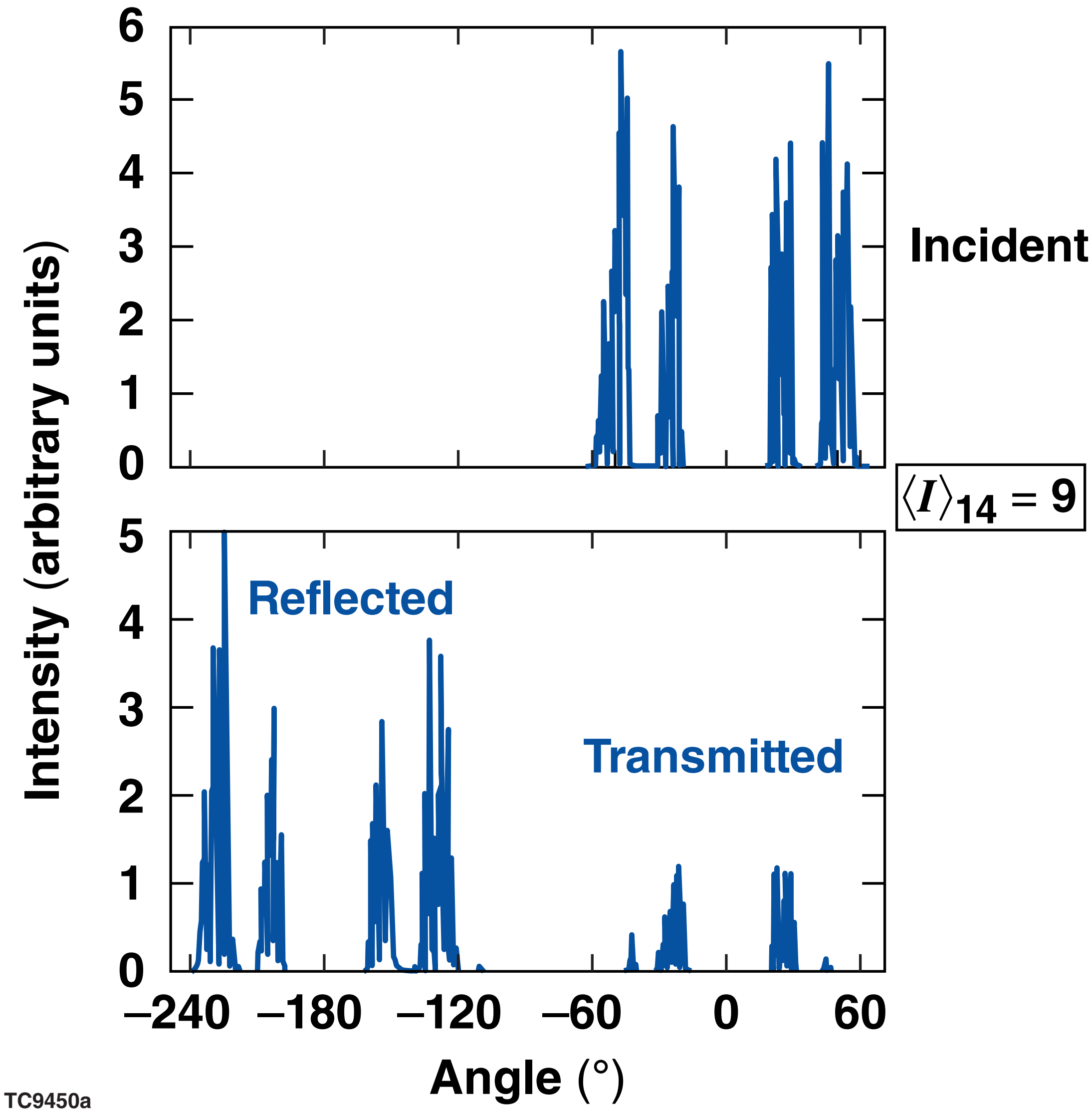
TC9446b

The interaction between beams incident at different angles leads to a broad spectrum of backscattered light

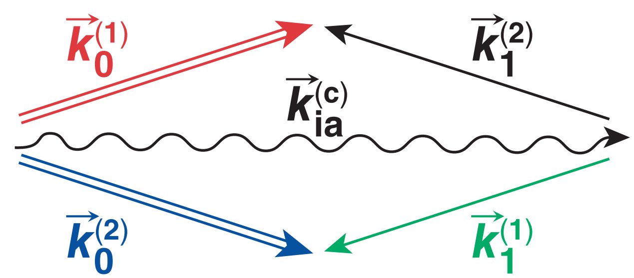


TC9449b

The interaction between multiple obliquely incident beams at moderate densities increases the backscatter



Common ion waves driven by multiple pairs of beams



TC9450a

Summary/Conclusions

For direct-drive ICF plasmas, scattering of light is driven by crossing laser beams that can generate common ion waves

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