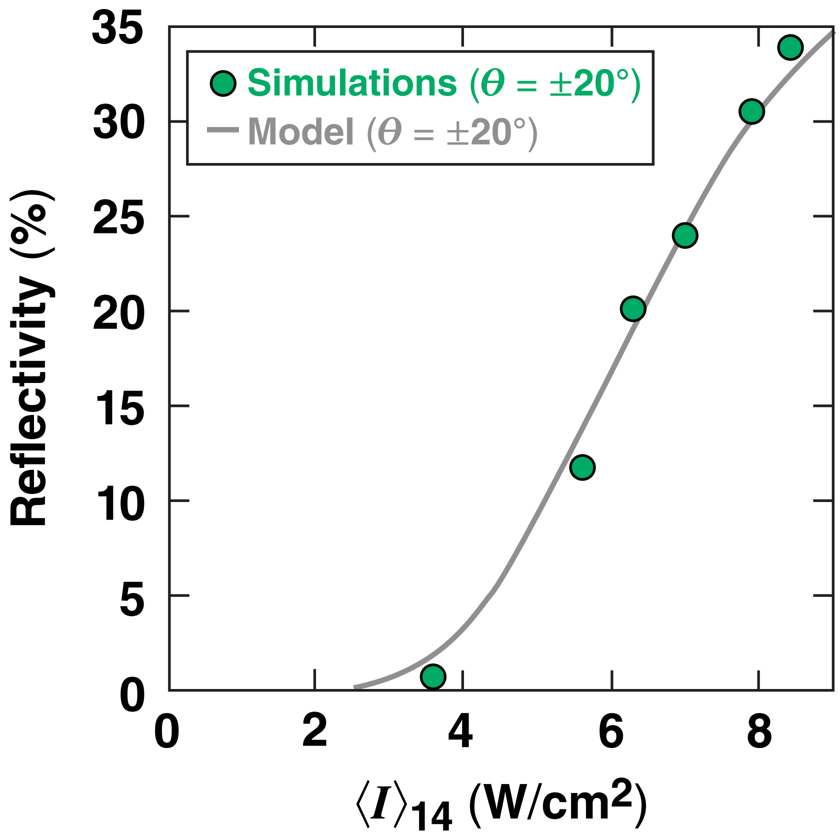
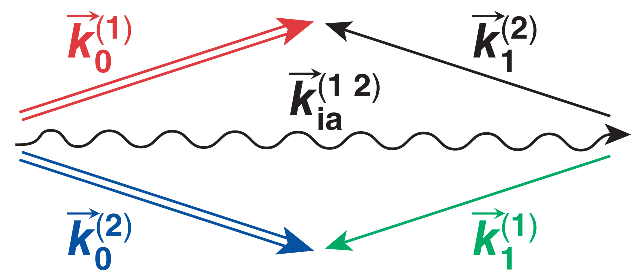
Scattering of Multiple Crossing Laser Beams in Direct-Drive Inertial Confinement Fusion (ICF) Plasmas





A. V. Maximov, J. F. Myatt,
R. W. Short, I. V. Igumenshchev,
D. H. Edgell, and W. Seka
University of Rochester
Laboratory for Laser Energetics

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Summary

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

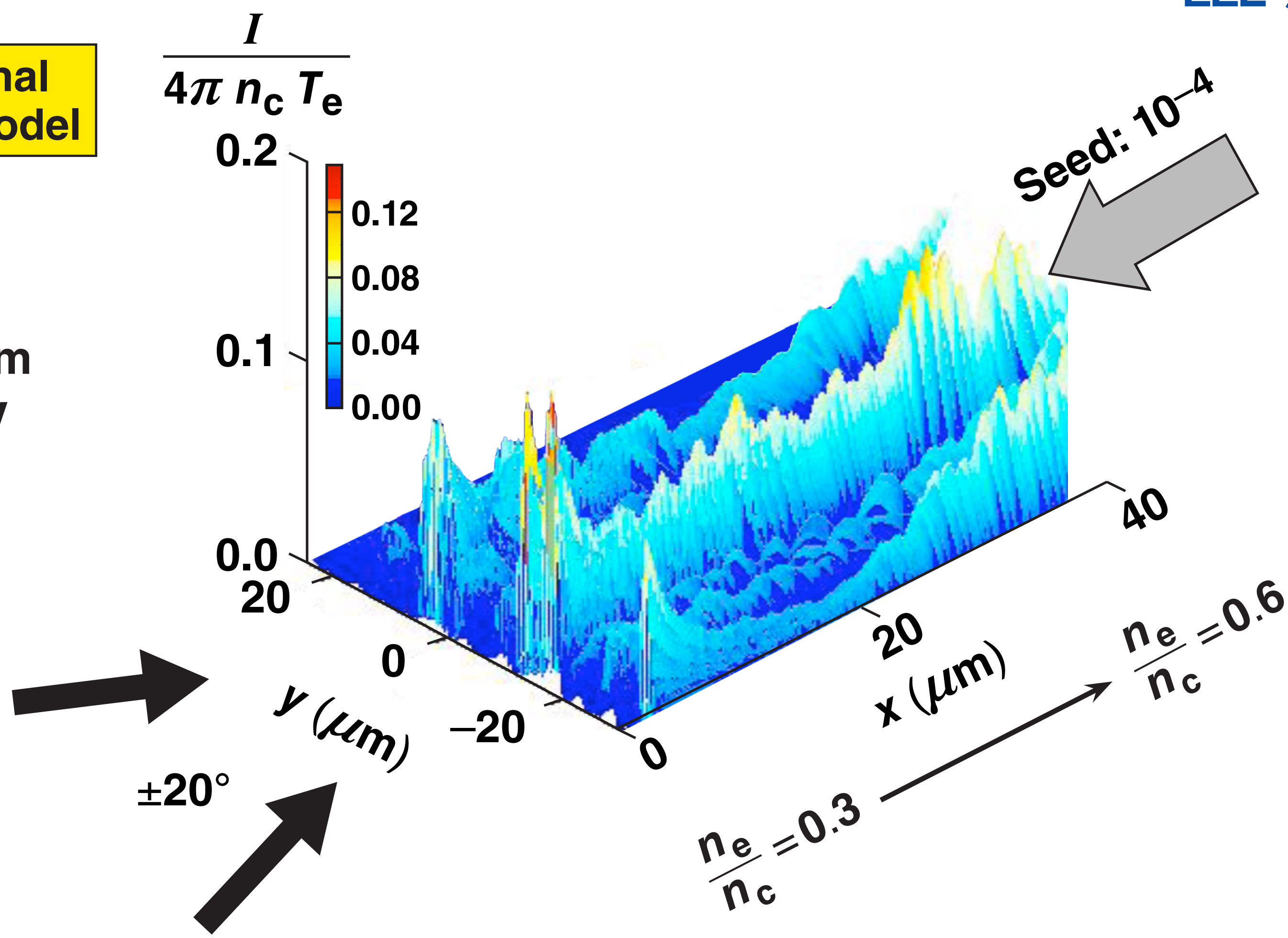
- Multiple crossing beams can drive common ion waves and scatter off them, increasing the reflectivity
- The laser speckle structure determines the angular distribution of scattered light and the scaling of reflectivity with intensity
- For multiple beams incident at different angles, multiple common ion-wave gratings can increase the reflectivity

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

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

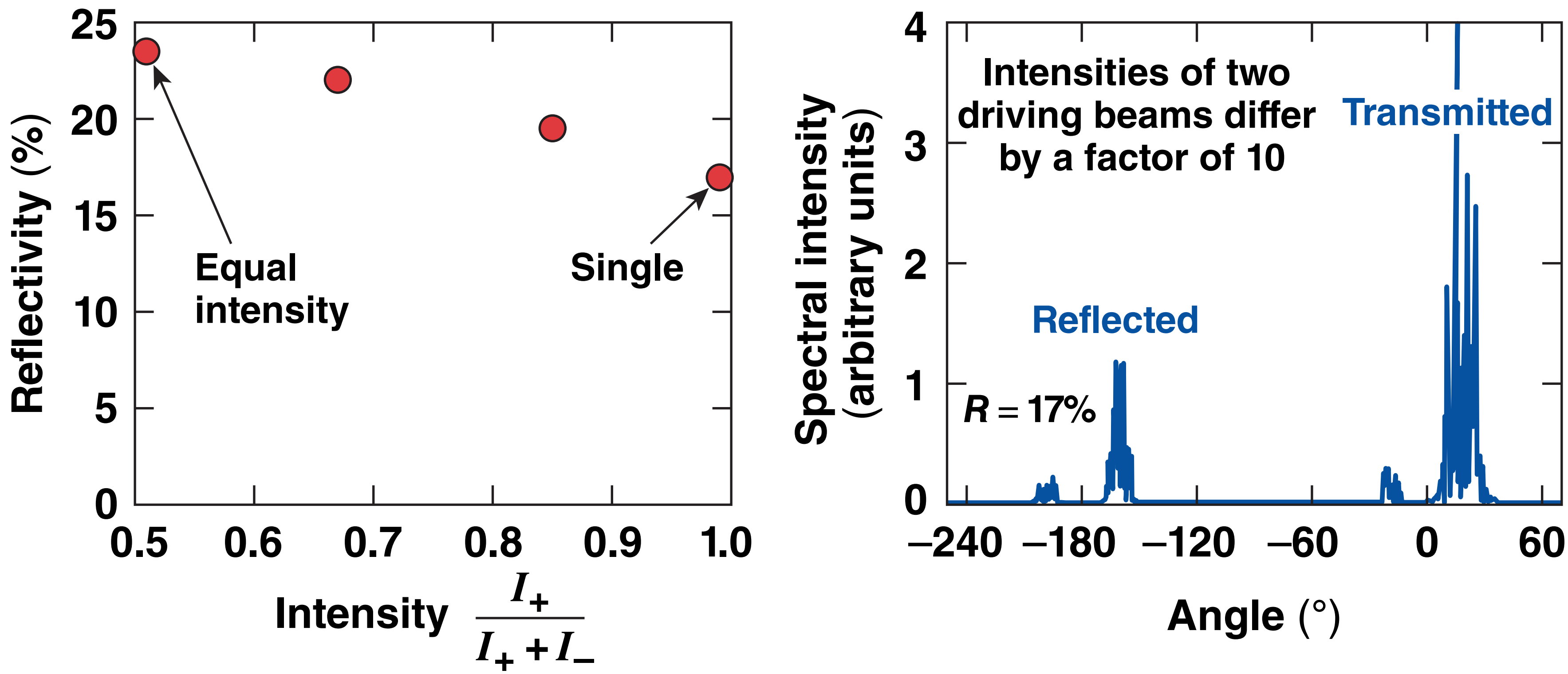
f/6 DPP



TC9444a

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

f/6 | $\langle I \rangle_{14} = 7$



At $\langle I \rangle_{14} = 3.5$ no reflectivity

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

Interaction in intense hot spots

TC9445b

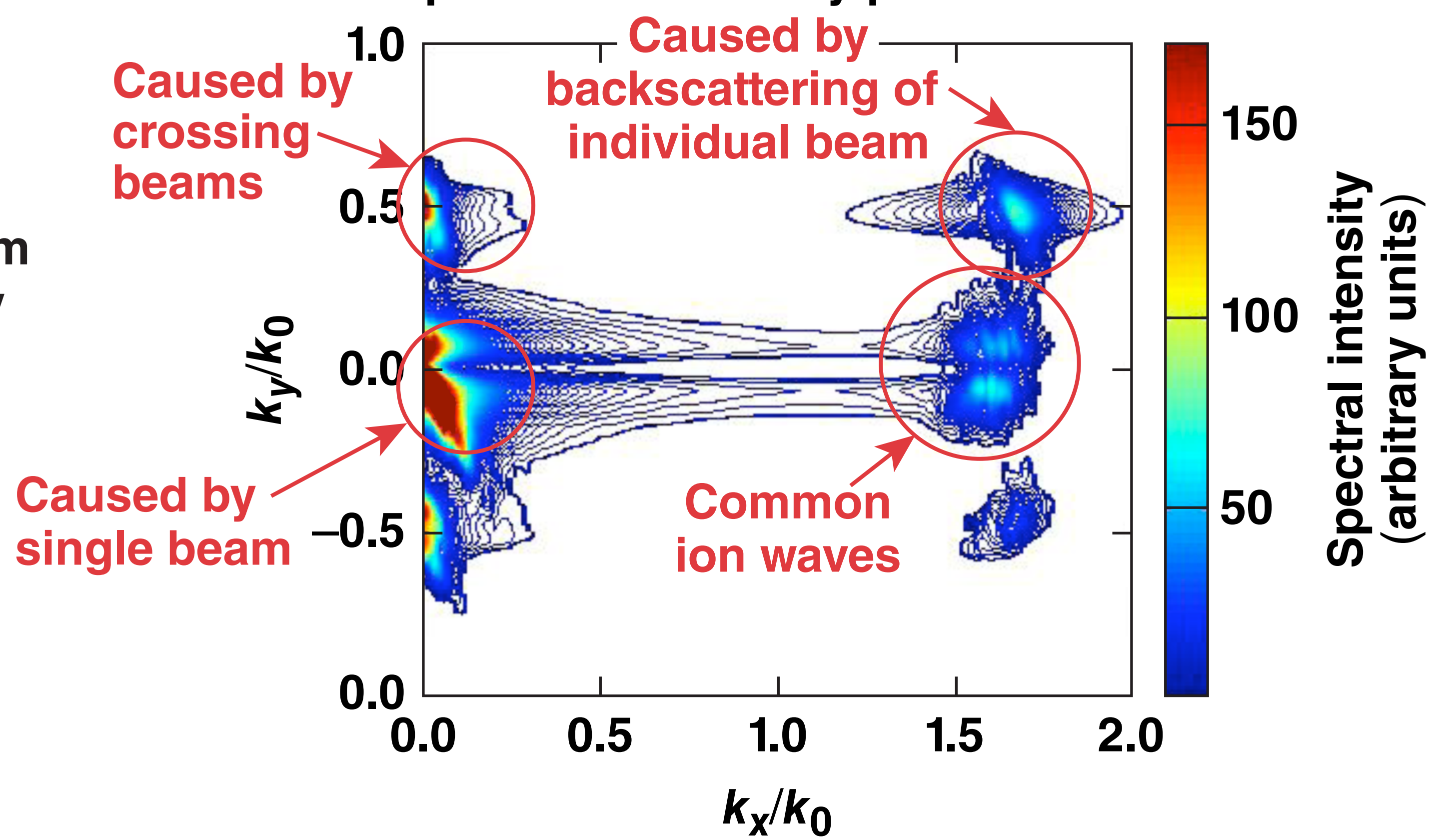
The interaction of incoherent crossing laser beams with plasmas produces a broad spectrum of low-frequency density perturbations

$\boxed{\langle I \rangle_{14} = 8}$

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

$\boxed{f/6}$

Spectrum of density perturbations

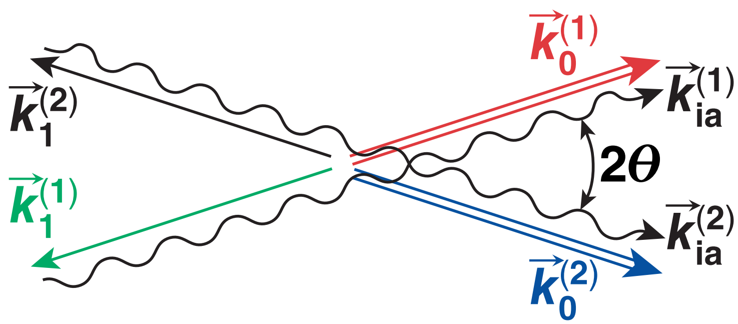


Laser beams can share density perturbations.

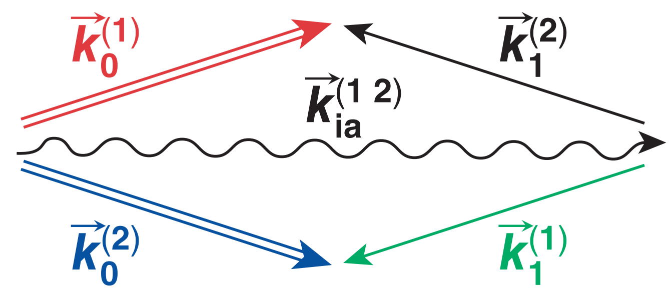
TC9448c

Crossing laser beams can scatter off common ion waves driven by multiple beams

Backscattering of individual beams



Scattering off common ion waves

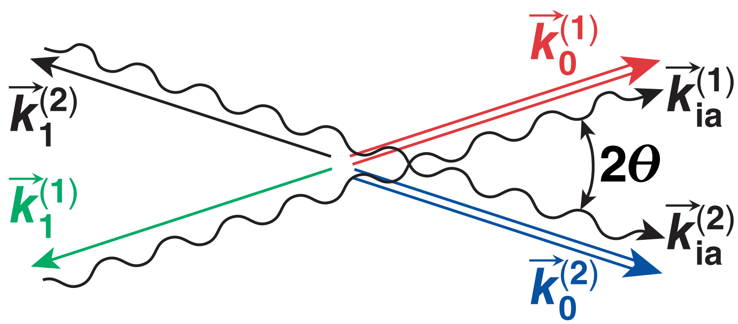


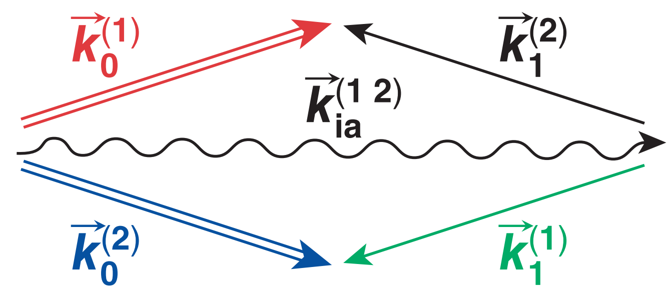
$$\frac{dE_1^{(1)}}{d\ell_1} = g\left[\vec{k}_{ia}^{(1\,2)}\right]\underbrace{\left[E_1^{(1)}E_0^{(2)*} + E_1^{(2)}E_0^{(1)*}\right]}E_0^{(2)} + g\left[\vec{k}_{ia}^{(1)}\right]\underbrace{\left|E_0^{(1)}\right|^2 E_1^{(1)}}$$

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

Scattering is possible in the direction opposite to the weaker beam.

Resonant conditions for common ion waves depend on the angle between driving laser beams





$$g\left[\vec{k}_{ia}\right] = \frac{\omega_0^2}{16\pi n_c^2 T_e c^2} \times \frac{n_e k_{ia}^2 c_{ia}^2}{2\nu_i \omega_{ia} + i\left[\left(\omega_{ia} + \vec{k}_{ia}\vec{v}_0\right)^2 - k_{ia}^2 c_{ia}^2\right]} \times \frac{1}{2k_{0x}}$$

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

TC10381

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

Reflectivity

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

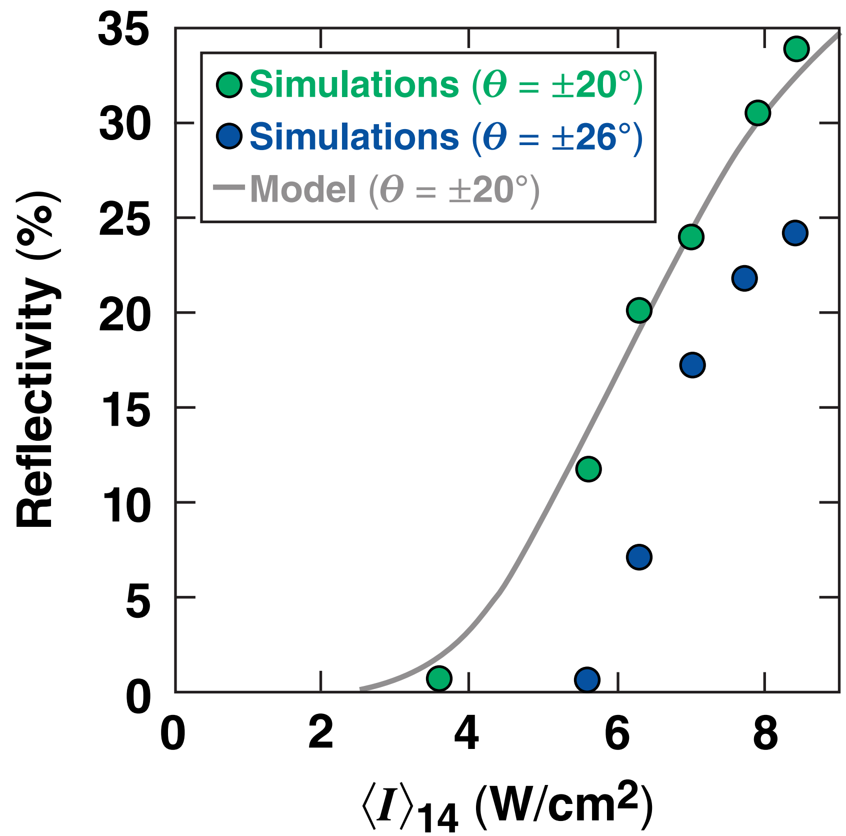
where

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

for the saturation R_{sat}*

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

ε – seed

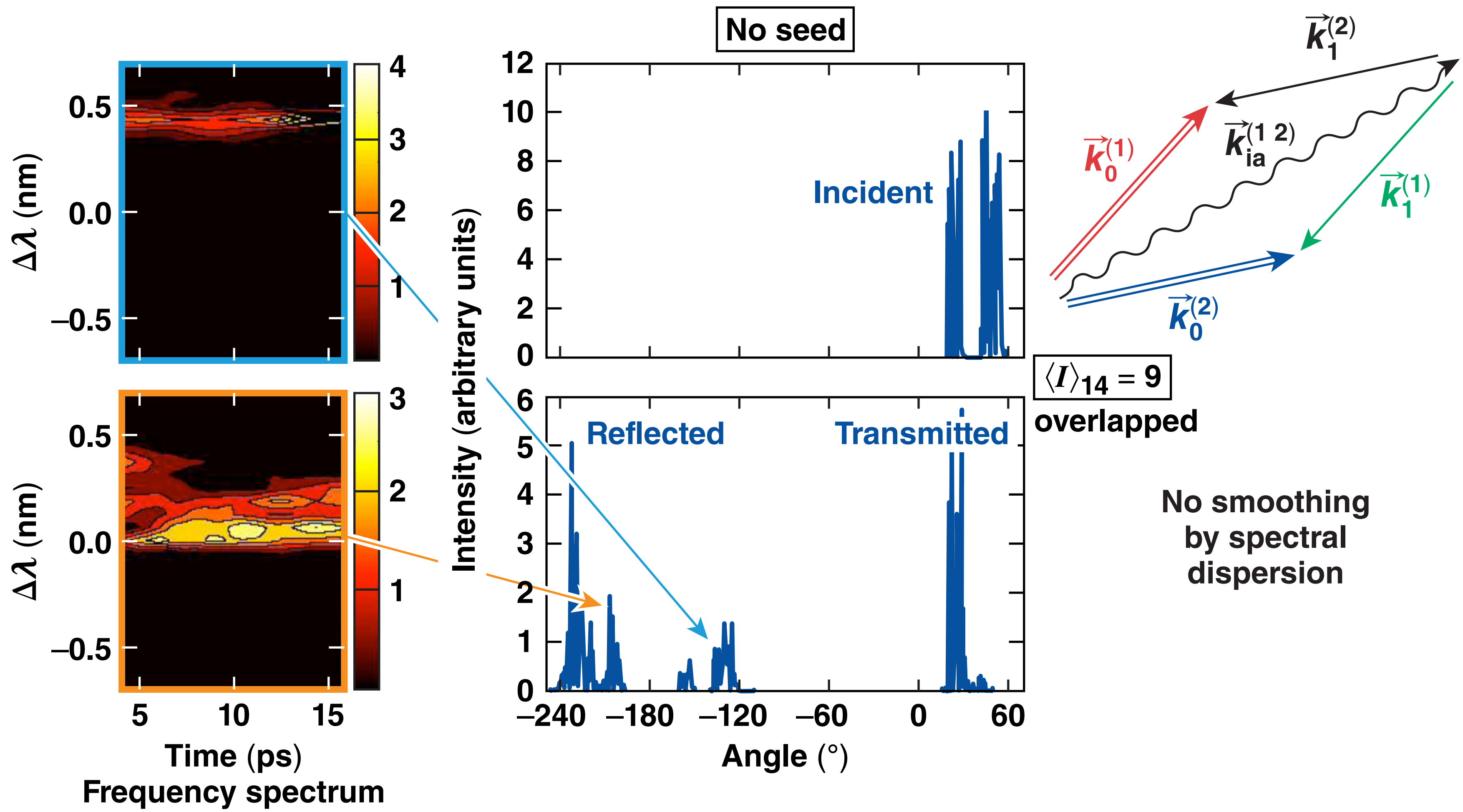


Coupling via common grating is weaker for larger θ

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

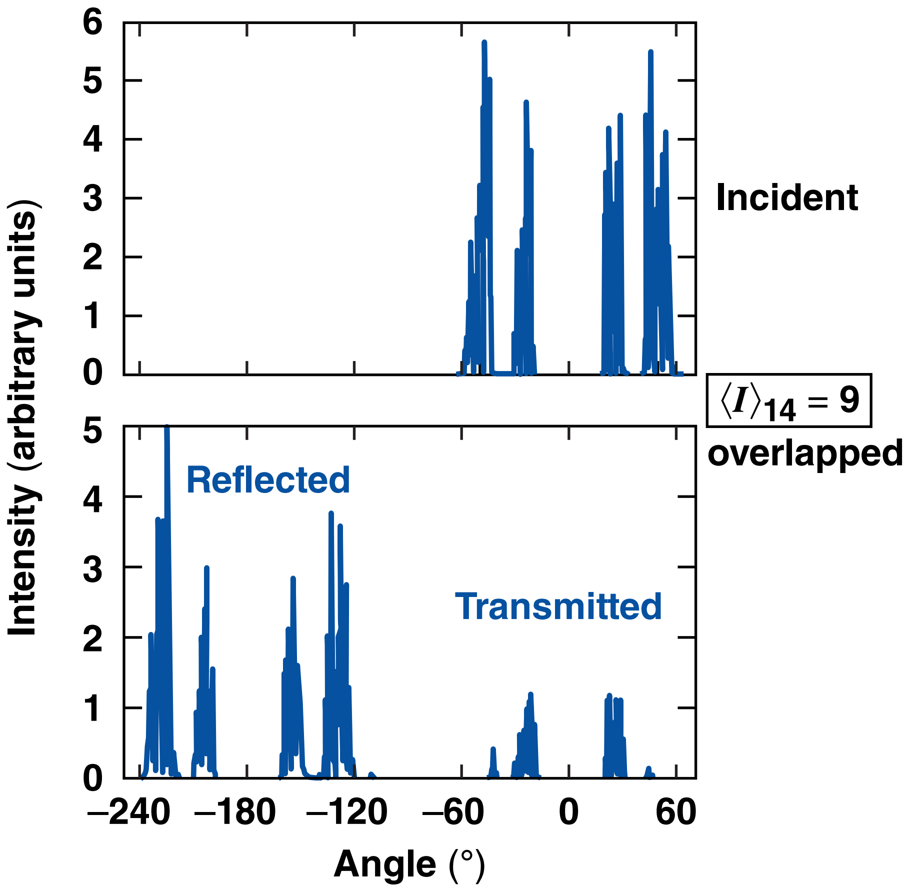
TC9446c

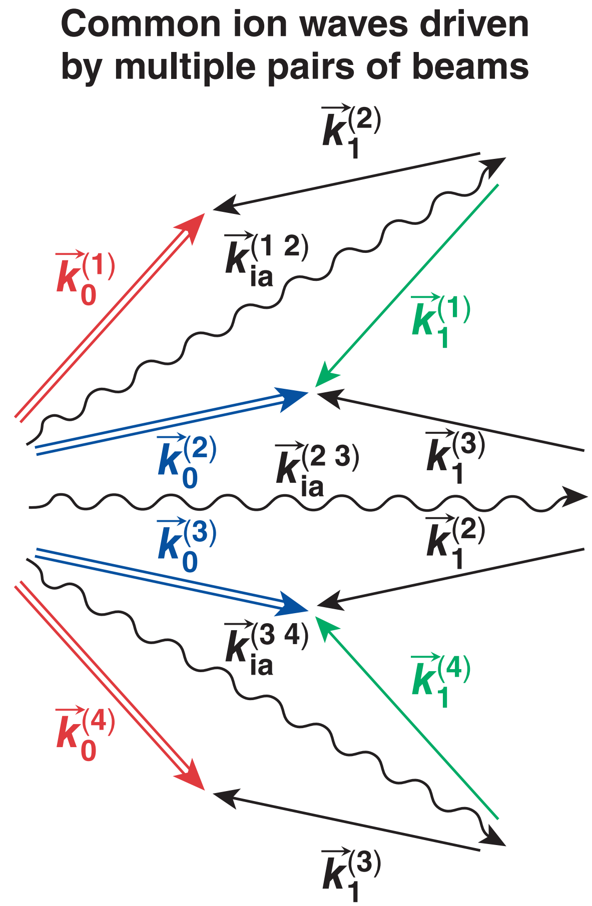
The interaction between beams incident at different angles can generate common ion waves



TC9449c

The interaction between multiple obliquely incident beams at moderate densities increases the backscatter as the result of sharing multiple common ion waves





TC9450b

Multiple common ion waves can be close to resonant.

Summary/Conclusions

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