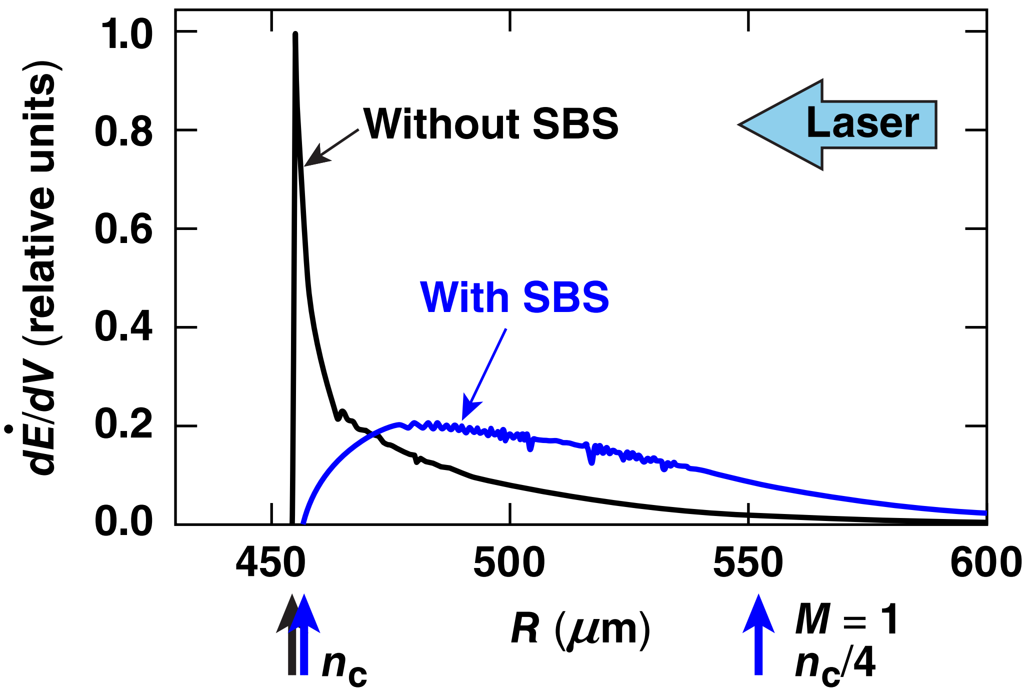
Modeling Crossed-Beam Energy Transfer in Implosion Experiments on OMEGA

Simulated laser absorption



I. V. Igumenshchev
University of Rochester
Laboratory for Laser Energetics

51st Annual Meeting of the
American Physical Society
Division of Plasma Physics
Atlanta, GA
2–6 November 2009

Summary

Inclusion of crossed-beam energy transfer in simulations of OMEGA implosions significantly improves agreement with absorption and timing data

- A self-consistent algorithm* for crossed-beam energy transfer has been developed and implemented in the radiative-hydrodynamic code *LILAC*
- Simulations show significant beam-to-beam energy transfer that reduces the laser absorption and requires a modification of the thermal transport model
- Efficient light scattering occurs in the regions with $n_e \sim 0.1$ to $0.5\ n_c$ and involves mainly light from the central part of the laser beam**

*See D. H. Edgell (JO5.00014).
**See A. Shvydky (UO5.00009).

Collaborators

D. H. Edgell

V. N. Goncharov

W. Seka

A. V. Maximov

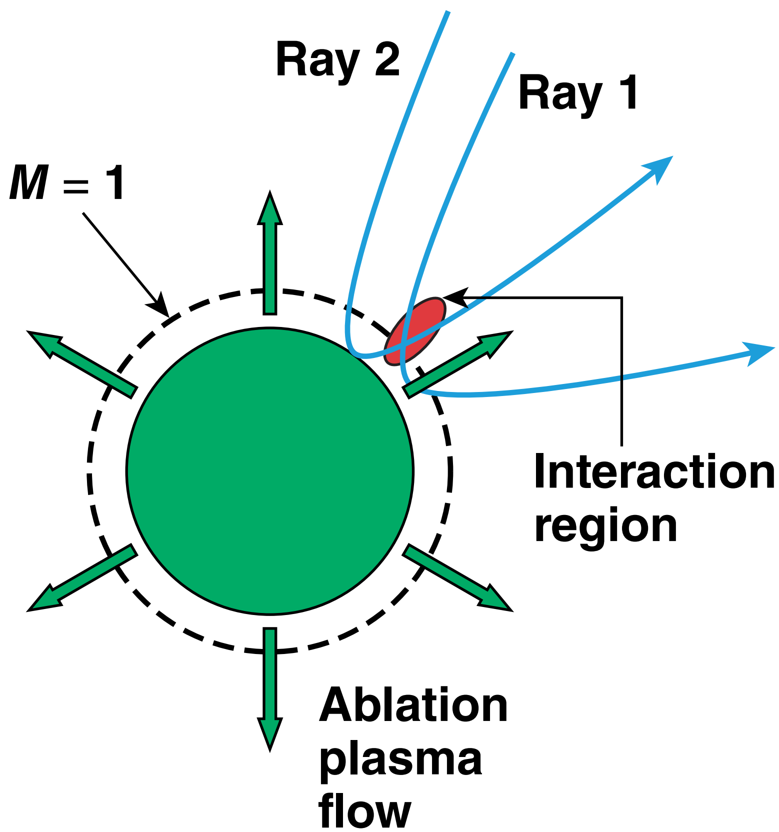
J. F. Myatt

A. Shvydky

J. A. Delettrez

University of Rochester
Laboratory for Laser Energetics

Beam-to-beam energy transfer in direct-drive implosions occurs near the transonic ($M = 1$) region

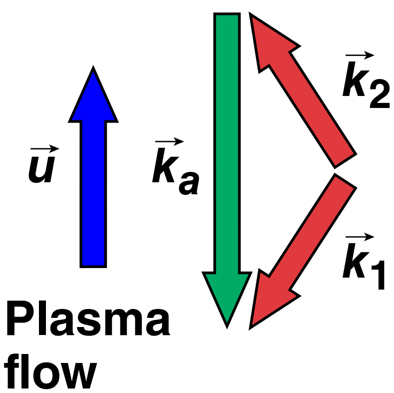


- The transfer takes place through the stimulated Brillouin scattering (SBS) process
- Incoming light (Ray 1)
  - typically loses energy
- Outgoing light (Ray 2)
  - typically gains energy

- **The reflected light bypasses the highest absorbed region near the turning point that can significantly reduce the overall energy absorption and target drive**

TC8625

The model of energy transfer between two crossing laser beams involves a steady resonantly induced ion-acoustic wave



$$\begin{cases} \vec{k}_1 = \vec{k}_2 + \vec{k}_a \\ \omega_1 = \omega_2 + \omega_a \end{cases}$$

$I^{(1)}$ – probe-beam intensity

$I^{(2)}$ – pump-beam intensity

Beam intensity change due to SBS:*

$$I^{(1)} = I_0^{(1)} \exp\left(\eta \int L^{-1} d\ell\right); \quad \eta = 0-1$$

$$L^{-1} = 3 \times 10^2 \frac{n/n_c}{\left(1-n/n_c\right)} \frac{\lambda_{\mu m} I_{14}^{(2)}}{f(Z)\, T_{keV}} \frac{P(\chi)}{\tilde{\nu}_a} \text{ cm}^{-1}$$

$$P(\chi) = \frac{\tilde{\nu}_a^2 \chi}{\tilde{\nu}_a^2 \chi^2 + \left(1-\chi^2\right)^2}; \; \chi = -\frac{\omega_a}{k_a c_a} + \frac{\vec{k}_a \cdot \vec{u}}{k_a c_a}$$

Damping coefficient: $\tilde{\nu}_a = \dfrac{\nu_a}{k_a c_a} \approx 0.2$ (CH plasma)

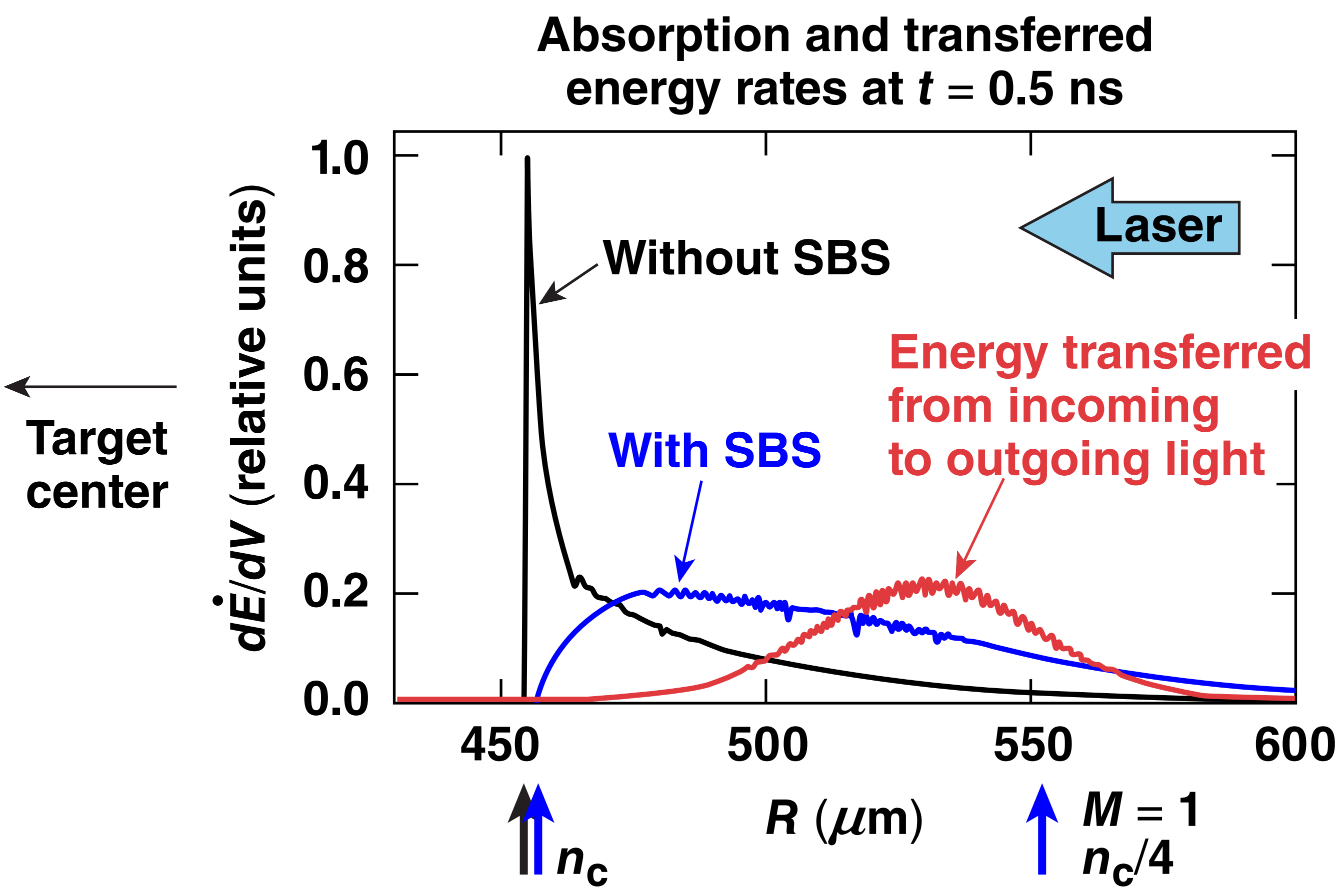
*C. J. Randall *et al.*, Phys. Fluids 24, 1474 (1981); J. A. F. Hittinger *et al.*, J. Comput. Phys. 209, 695 (2005).

TC8626

Scattered-light simulations include the integral effect of all crossed beams and consider the 3-D distribution of ray trajectories

- Plasma flow is assumed to be spherically symmetric (1-D)
- An infinite number of laser beams (instead of OMEGA's 60 beams) are assumed to be uniformly distributed over the sphere
- Each beam is characterized by a super-Gaussian profile with the index $n = 4$ (OMEGA SG4 phase plates)
- Energy conservation is enforced by normalizing the total energy gain of outgoing rays with respect to the total energy loss of incoming rays

Simulations show that less energy is absorbed near the critical surface due to SBS effects



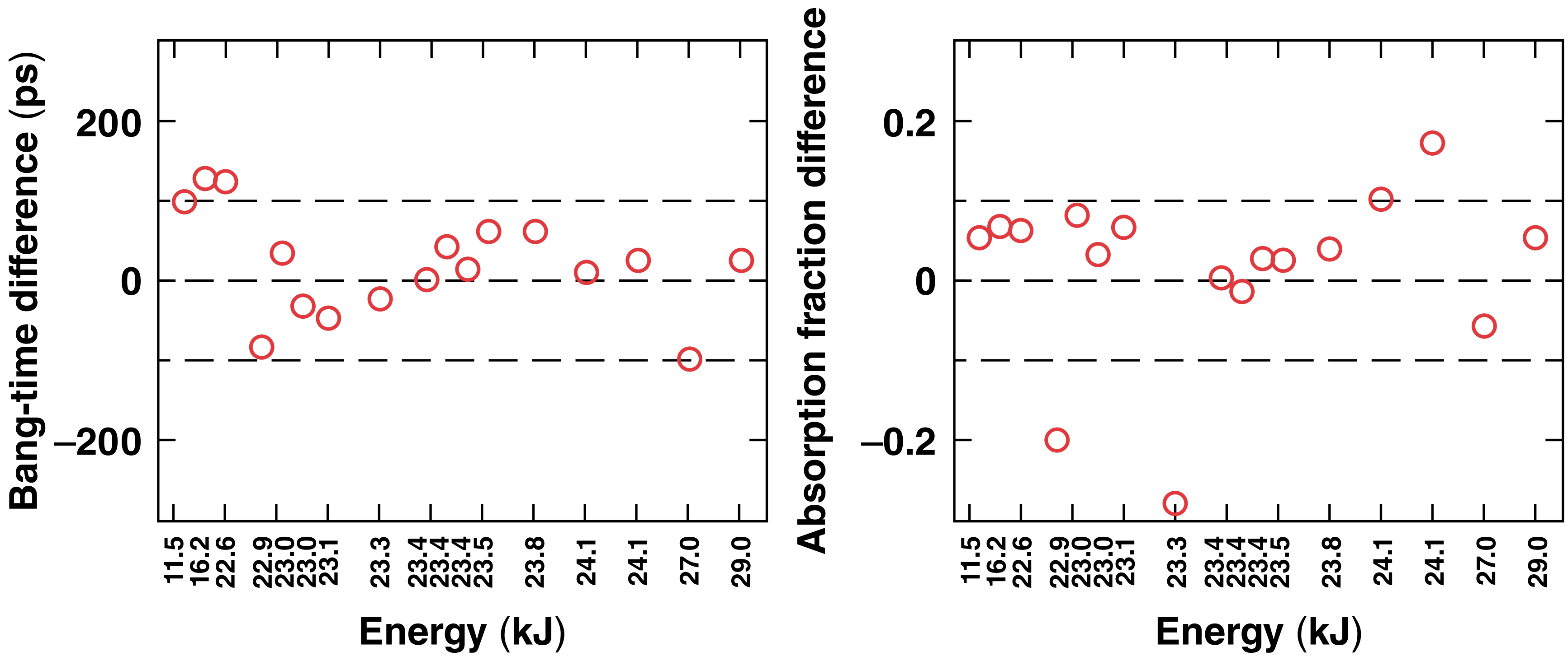
- Plastic-shell target
- 1-ns square pulse
- $I \sim 10^{15}$ W/cm^2

Reflected light bypasses the highest absorption region eliminating the absorption peak.

TC8628

Results of implosion simulations with SBS effects have demonstrated a good agreement with bang-time and laser absorption measurements

A sample of 1-ns square pulse, warm plastic-shell implosions

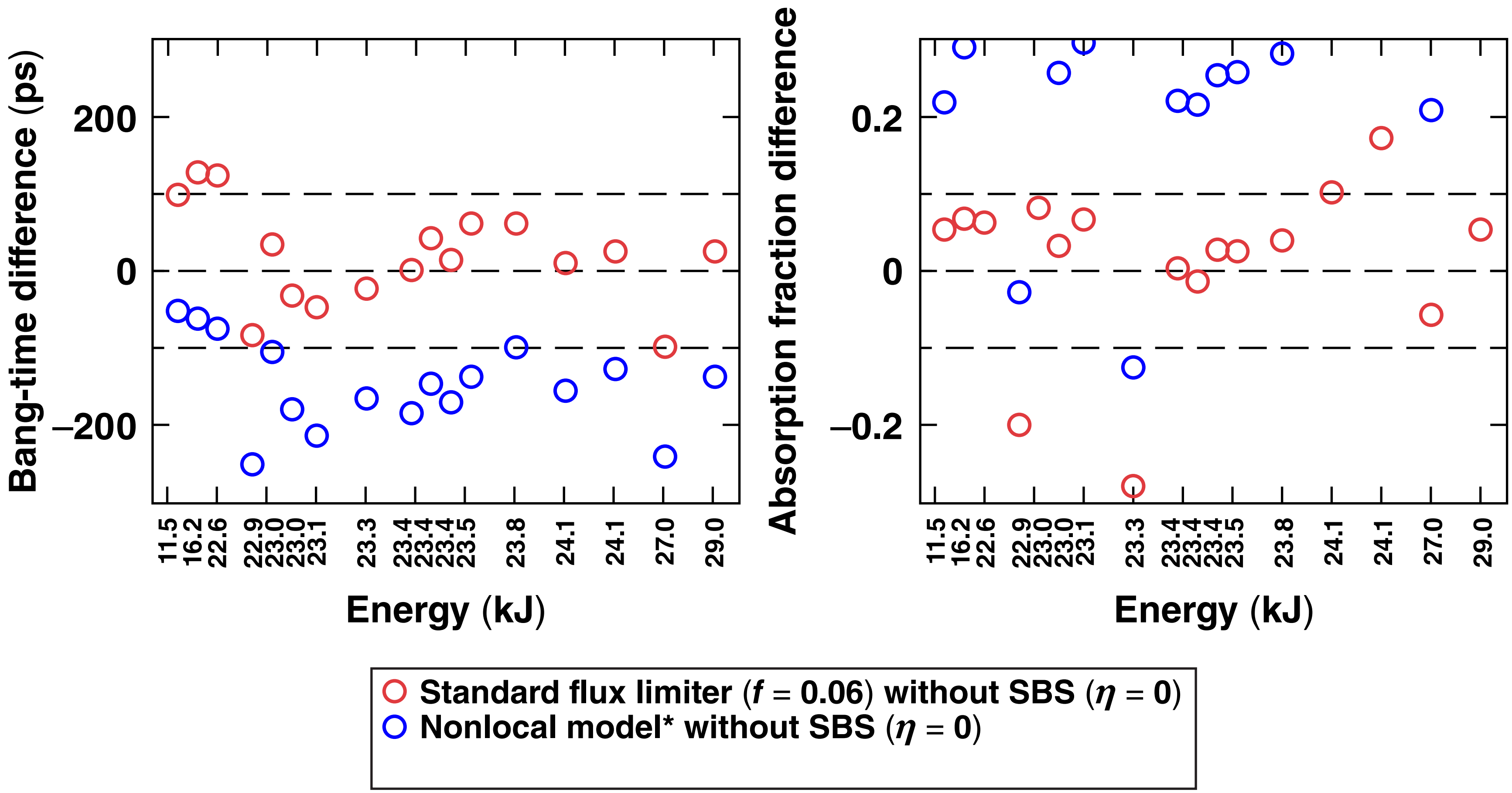


○ Standard flux limiter ($f = 0.06$) without SBS ($\eta = 0$)

TC8630

Results of implosion simulations with SBS effects have demonstrated a good agreement with bang-time and laser absorption measurements

A sample of 1-ns square pulse, warm plastic-shell implosions

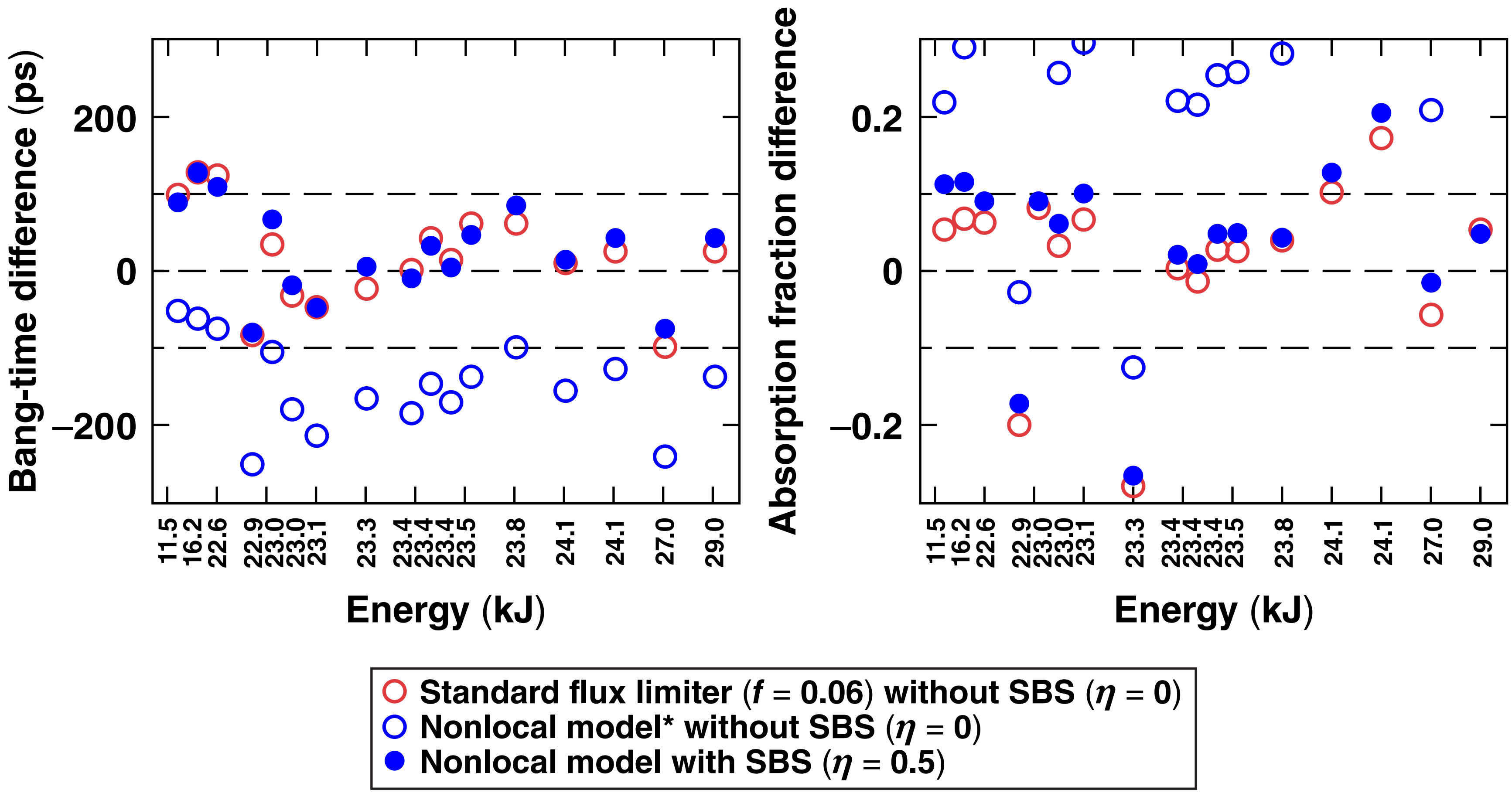


TC8630

*V. N. Goncharov *et al*., Phys. Plasmas 15, 056310 (2008).

Results of implosion simulations with SBS effects have demonstrated a good agreement with bang-time and laser absorption measurements

A sample of 1-ns square pulse, warm plastic-shell implosions



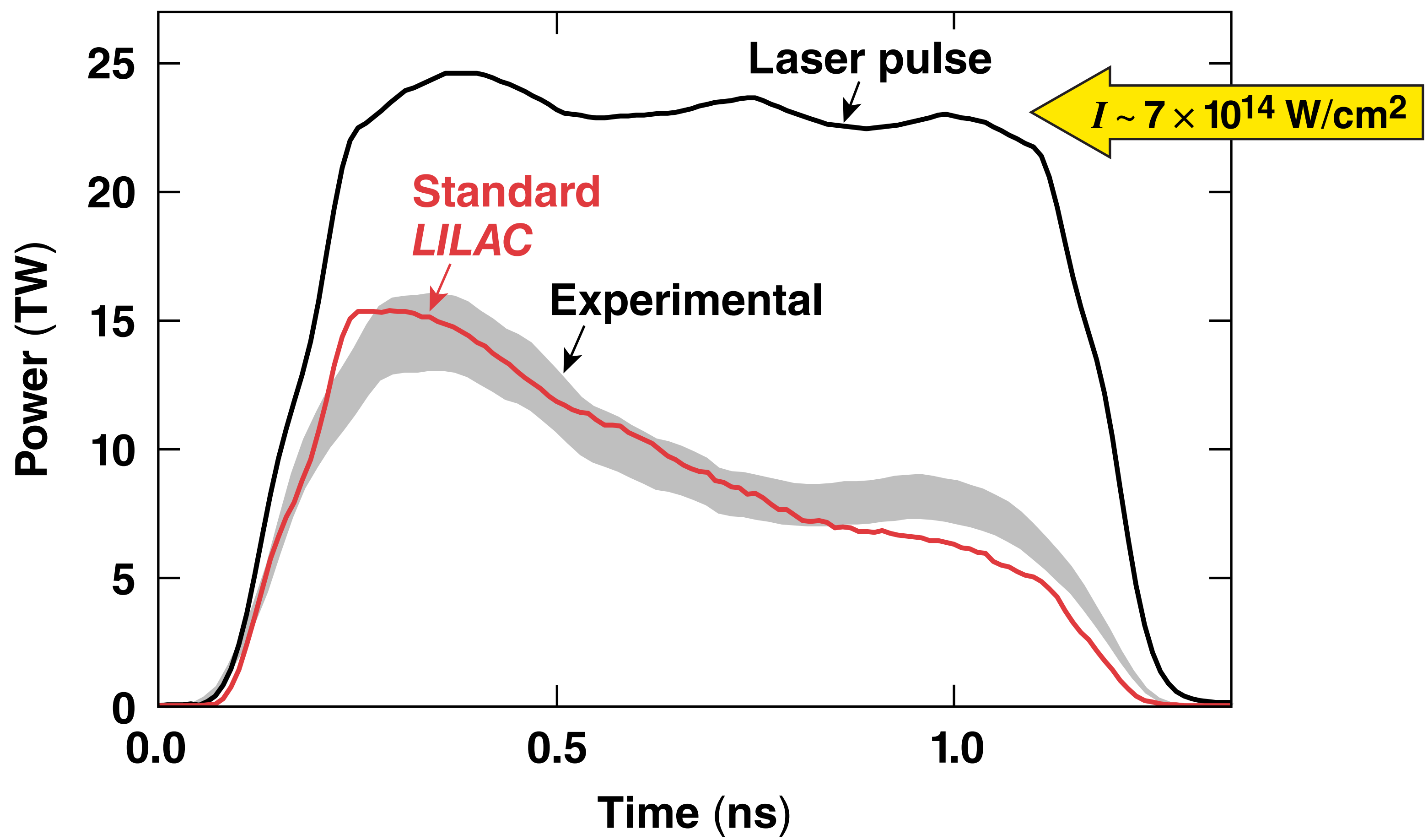
TC8630

*V. N. Goncharov *et al*., Phys. Plasmas 15, 056310 (2008).

SBS effects enhance the late-time reflection of laser light in agreement with experimental data

UR LLE

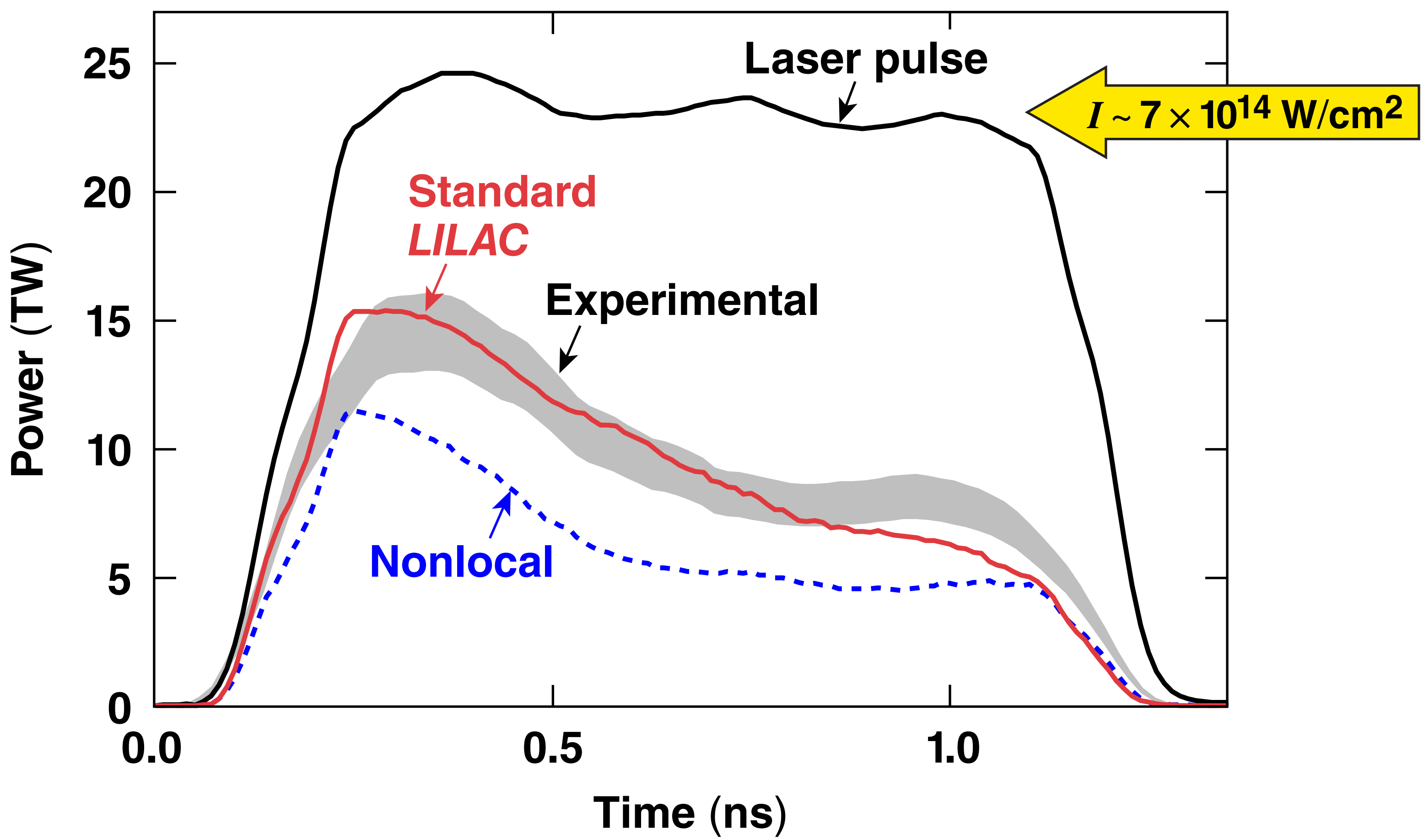
Reflection-light measurement and simulation for OMEGA shot 53309 (warm plastic-shell target)



TC8631

SBS effects enhance the late-time reflection of laser light in agreement with experimental data

Reflection-light measurement and simulation for OMEGA shot 53309 (warm plastic-shell target)

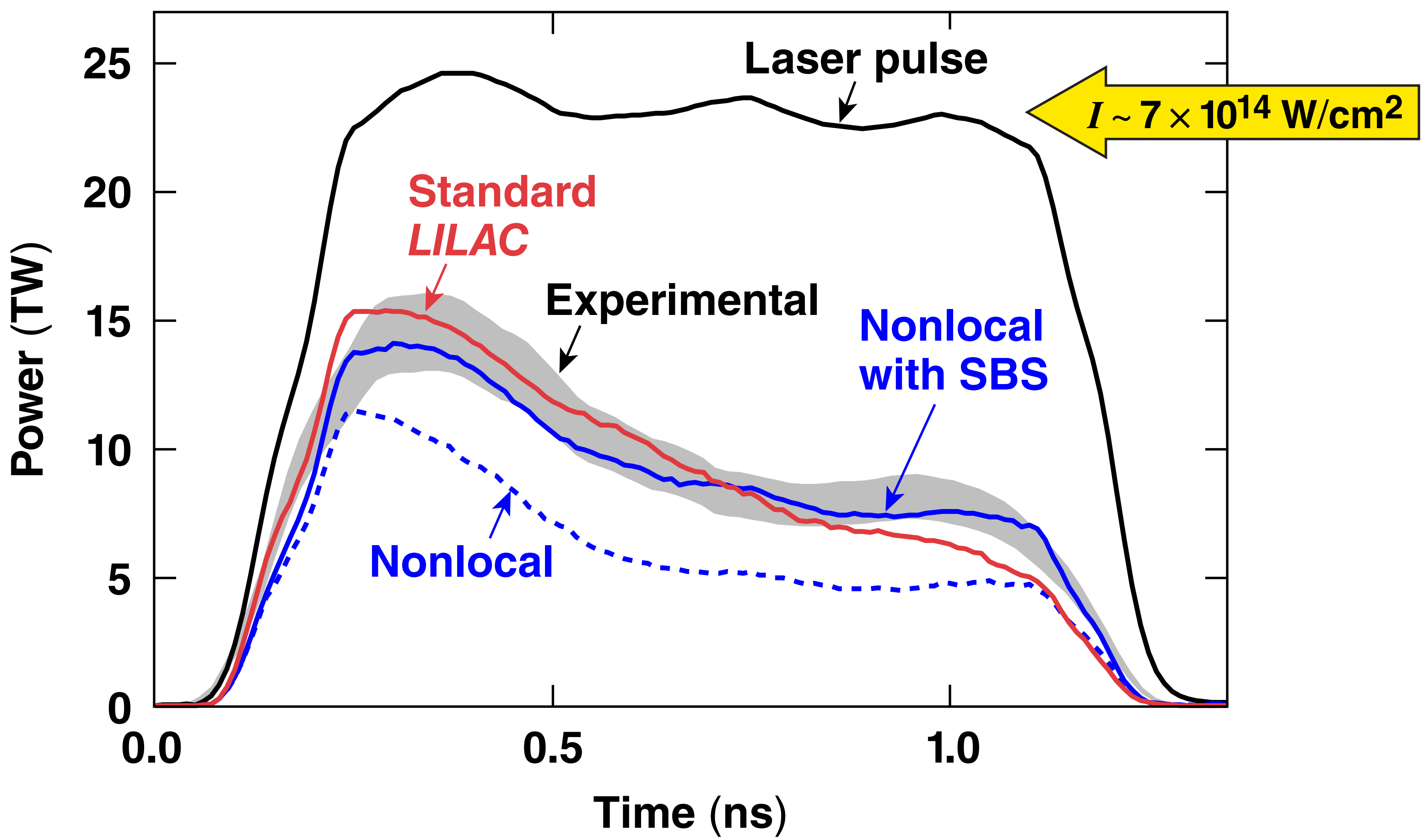


TC8631

SBS effects enhance the late-time reflection of laser light in agreement with experimental data

UR LLE

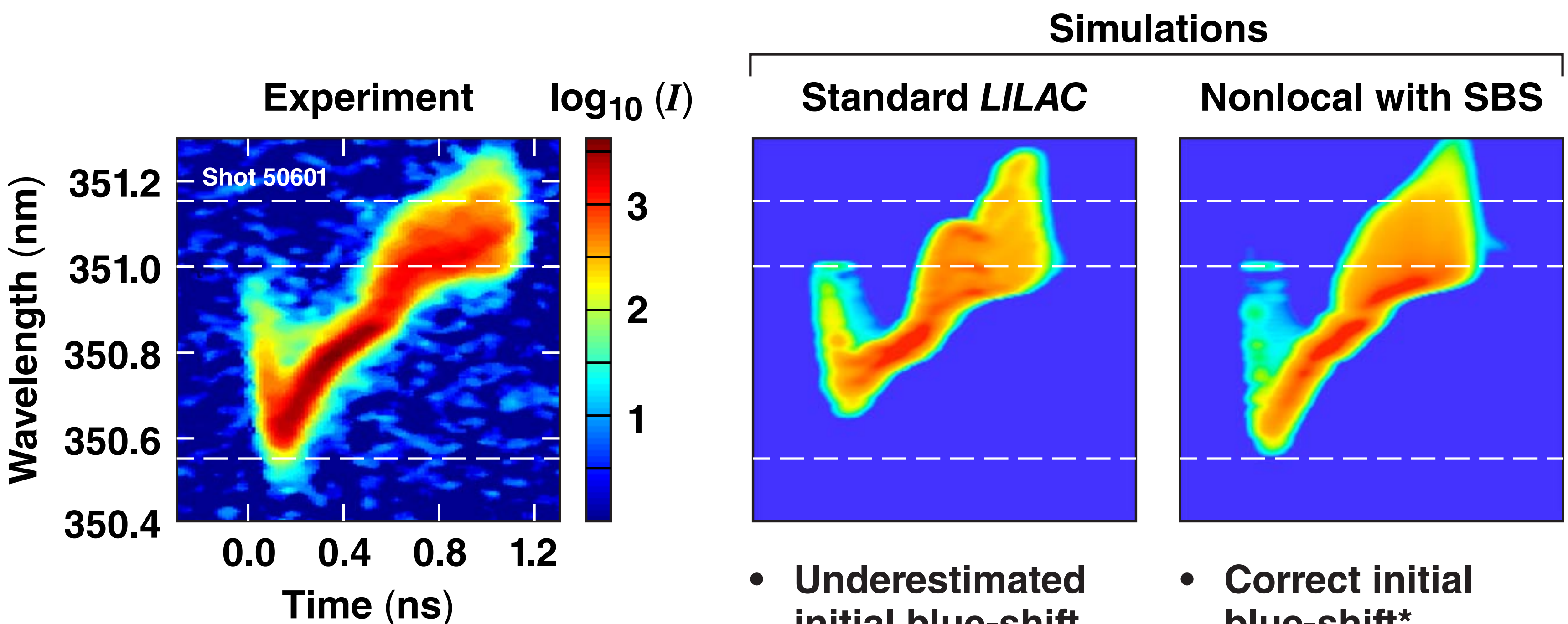
Reflection-light measurement and simulation for OMEGA shot 53309 (warm plastic-shell target)



TC8631

Time-resolved experimental spectra of scattered light are better explained by models with SBS effects

1-ns square pulse, warm plastic-shell implosion (OMEGA shot 50601)



Standard *LILAC*

- Underestimated initial blue-shift
- Incorrect overall shape

Nonlocal with SBS

- Correct initial blue-shift*
- Correct later-time red-shift due to SBS

TC8632

*D. H. Edgell *et al*., Bull. Am. Phys. Soc. 53, 168 (2008).

Summary/Conclusions

Inclusion of crossed-beam energy transfer in simulations of OMEGA implosions significantly improves agreement with absorption and timing data

UR LLE

- A self-consistent algorithm* for crossed-beam energy transfer has been developed and implemented in the radiative-hydrodynamic code *LILAC*
- Simulations show significant beam-to-beam energy transfer that reduces the laser absorption and requires a modification of the thermal transport model
- Efficient light scattering occurs in the regions with $n_e \sim 0.1$ to $0.5\ n_c$ and involves mainly light from the central part of the laser beam**

*See D. H. Edgell (JO5.00014).
**See A. Shvydky (UO5.00009).