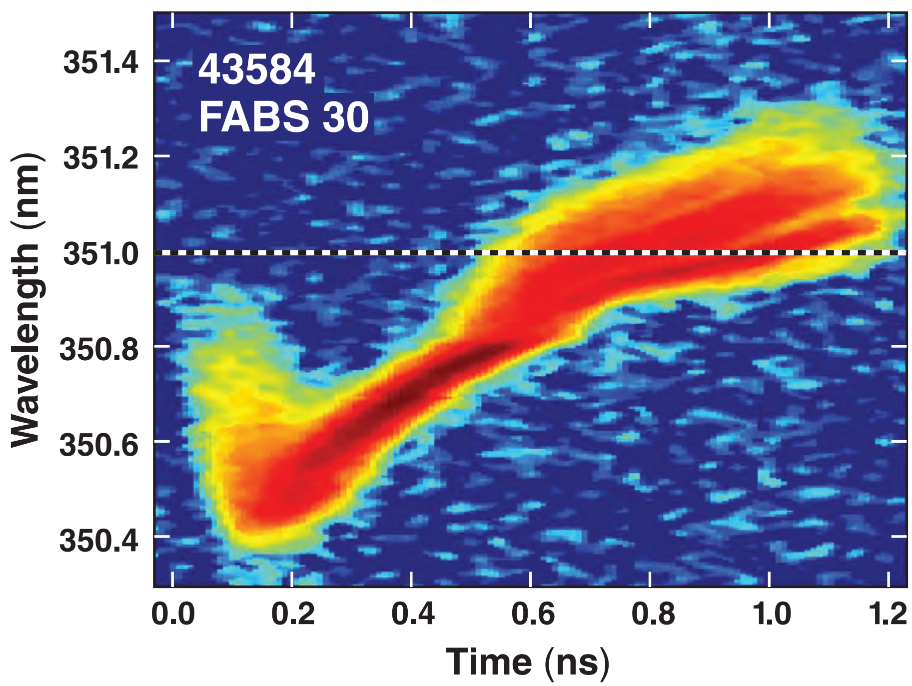
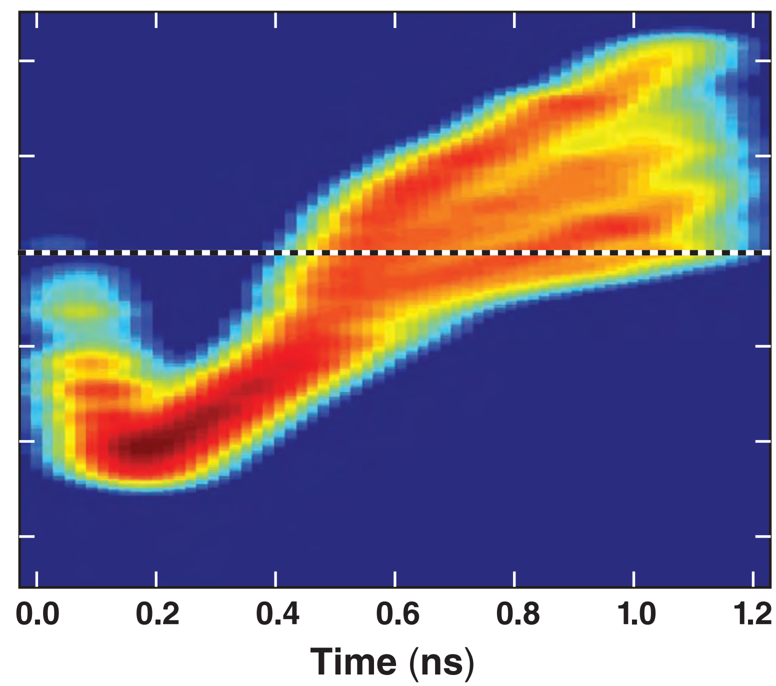
Scattered Laser-Light Spectroscopy in Direct-Drive Implosion Experiments

Experimental FABS Spectrum



Modeled FABS Spectrum



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Summary

Scattered-light modeling indicates that additional physics is needed in hydrocode coronal modeling

- FABS measures temporally and spectrally resolved scattered light from OMEGA implosions in the SBS range (351±1 nm)
- Time-dependent scattered-light spectra are modeled by a combination of hydrodynamic and ray-tracing codes
  - predicted spectra vary with the electron-heat transport model
  - no satisfactory predictions of both the spectral shifts and scattered power with same model
- Indicates some additional physics is occurring in the coronal plasma
  - enhanced absorption early in the pulse
  - enhanced scattering later in the pulse
  - nonlinear LPI cross-beam power transfer via EM-seeded SBS might explain both phenomena

Collaborators

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Motivation

The *time-dependent* absorbed fraction observed in OMEGA implosions typically does not match hydrocode predictions

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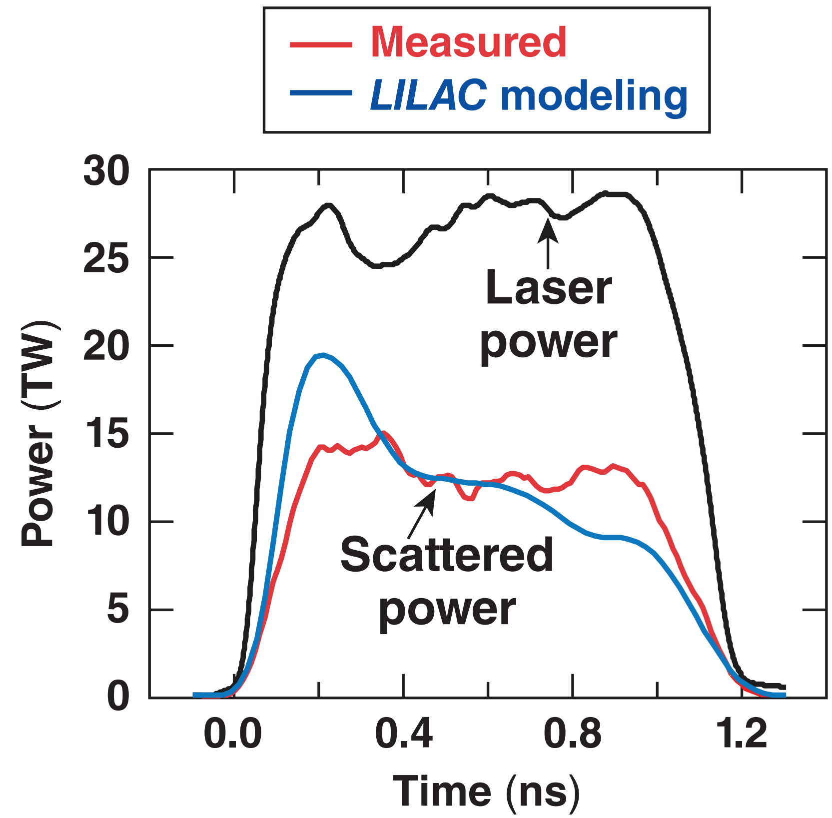
- Time-dependent absorbed fraction during OMEGA implosions is inferred from full-aperture backscatter station (FABS) diagnostic scattered-light measurements
- Measured *time-integrated* power usually matches modeling using *f* = 0.06 flux limiter



Detailed modeling of time-dependent scattered-light spectra has been developed to investigate discrepancies between predictions and FABS.

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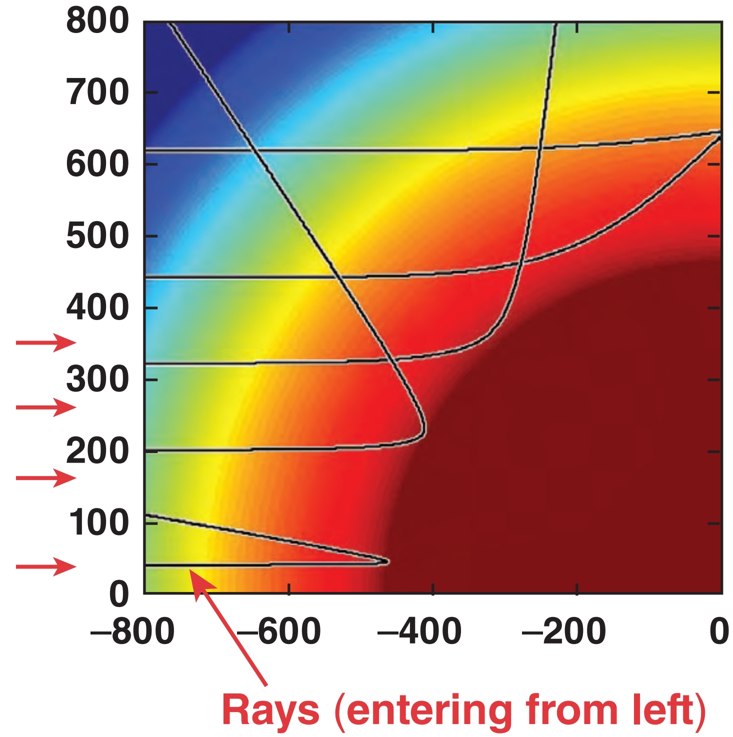
Modeling Scattered Spectra

Time-dependent scattered-light spectra are modeled for OMEGA implosions

- *LILAC*: 1-D hydrodynamic code predicts time-dependent implosion profiles
  - using different electron-heat transport models: fixed flux-limited, CEA nonlocal model,[1] Goncharov nonlocal model[2]
- *SAGERAYS*: Ray traces 351-nm-drive laser light through plasma and calculates spectral shift along each path[3]

$$\Delta\omega = -\omega_0 \frac{\partial \tau_f}{\partial t} = +\frac{\omega_0}{2c} \int \left(1 - \frac{n_e}{n_c}\right)^{-1/2} \frac{\partial}{\partial t}\left(\frac{n_e}{n_c}\right) ds$$

- MATLAB code calculates total spectrum collected by FABS from all 60 beams



[1]G. P. Schurtz, Ph. D. Nicolaï, and M. Busquet, Phys. Plasmas 7, 4238 (2000).
[2]V. Goncharov *et al.*, Phys. Plasmas 13, 012702 (2006).
[3]T. Dewandre, J. R. Albritton, and E. A. Williams, Phys. Fluids 24, 528 (1981).

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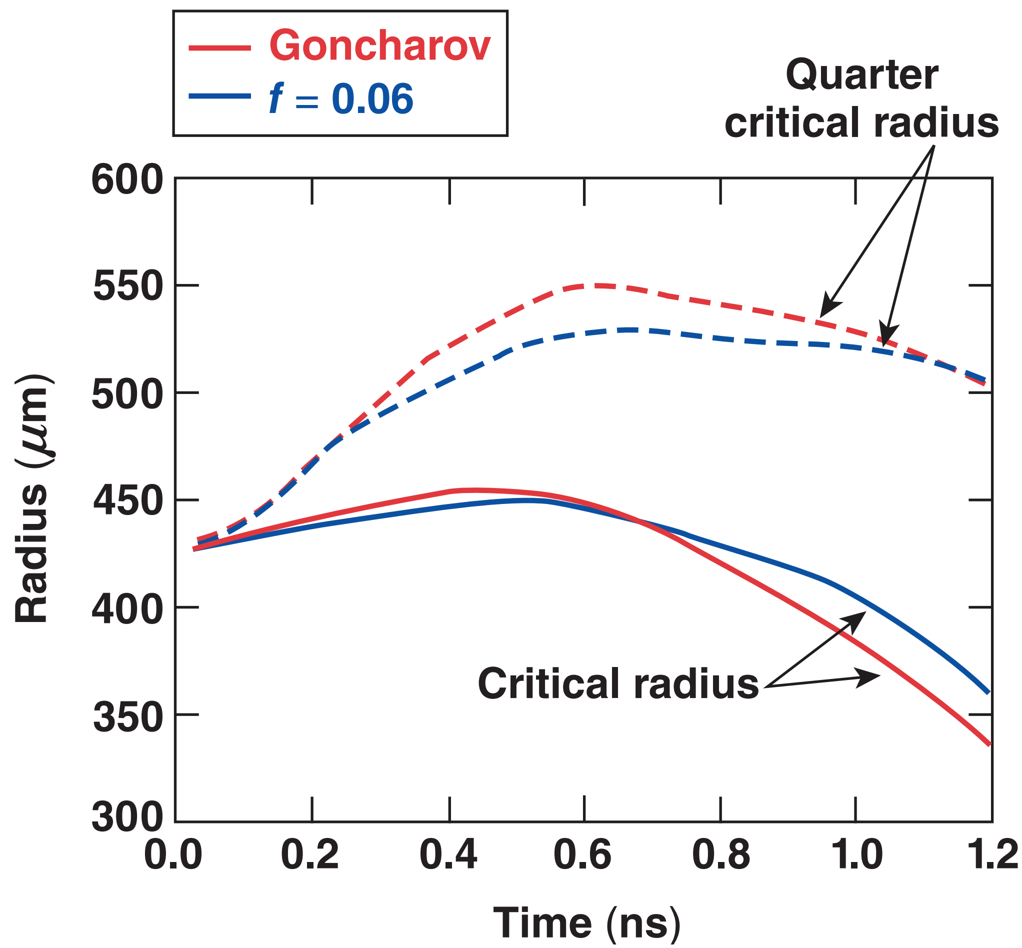
The heat transport model used by hydrocode significantly affects the plasma-density profiles and its rate of change

- The Goncharov nonlocal transport model[1] in comparison with the f = 0.06 fixed flux-limiter model transports more thermal energy inside the plasma critical surface
  - Lower corona temperature
  - More absorption in corona
  - More mass ablation
  - Higher plasma velocities
  - Longer coronal density scale lengths



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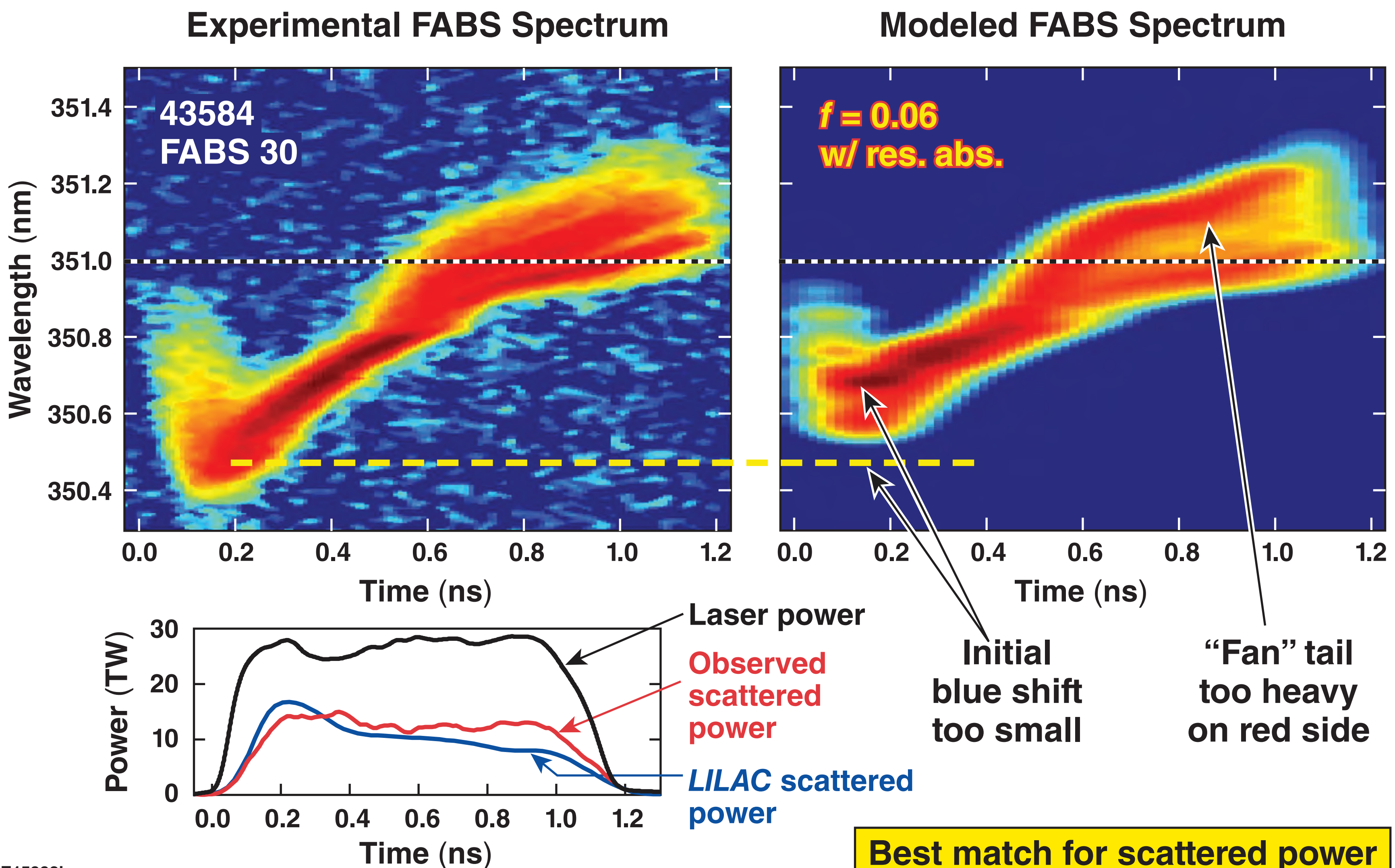
[1] V. Goncharov *et al.*, Phys. Plasmas 13, 012702 (2006).

Experimental Comparisons

Predicted spectral shifts vary significantly with the electron-heat transport model used by hydrocode



Best match for scattered power

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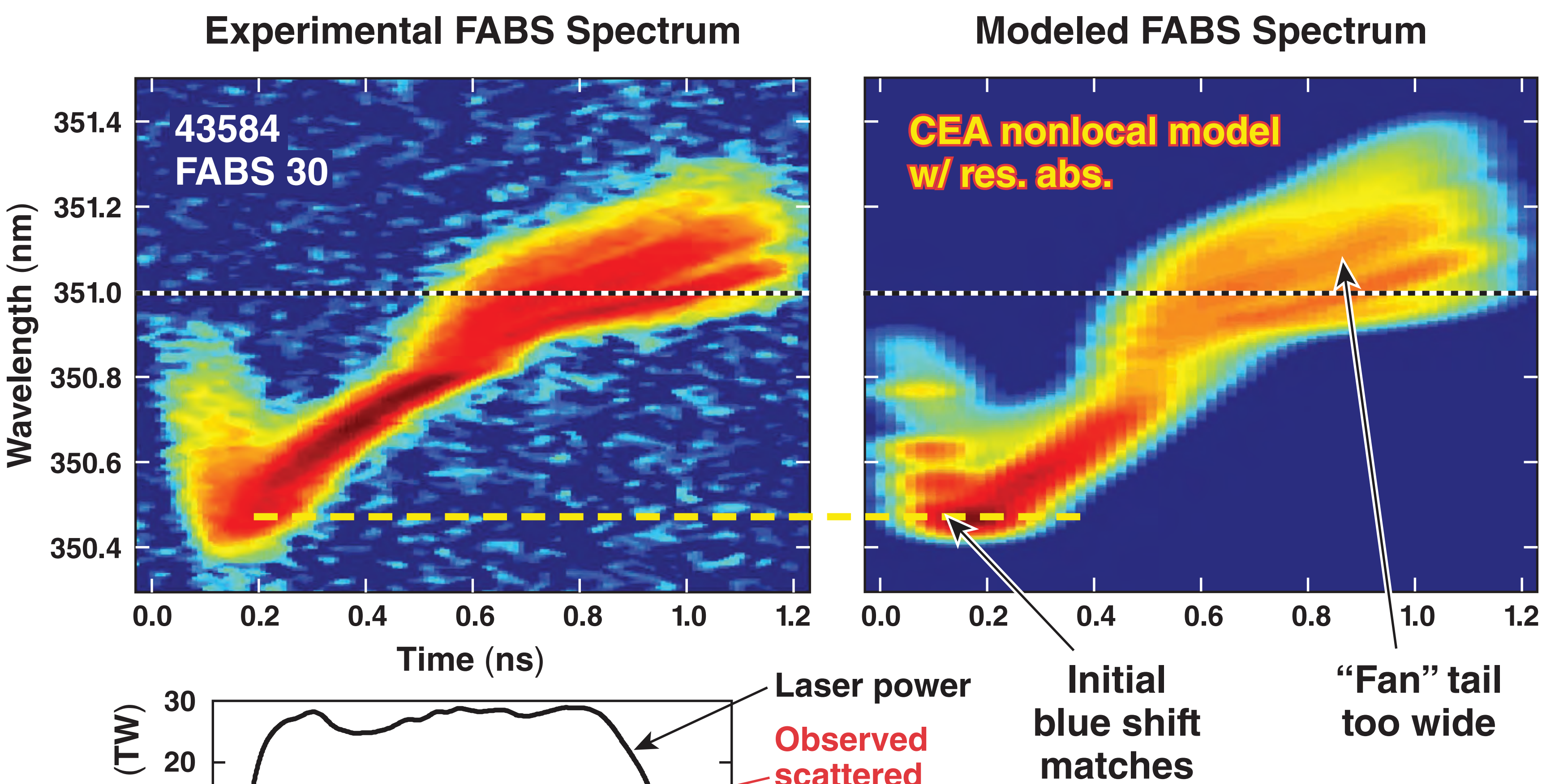
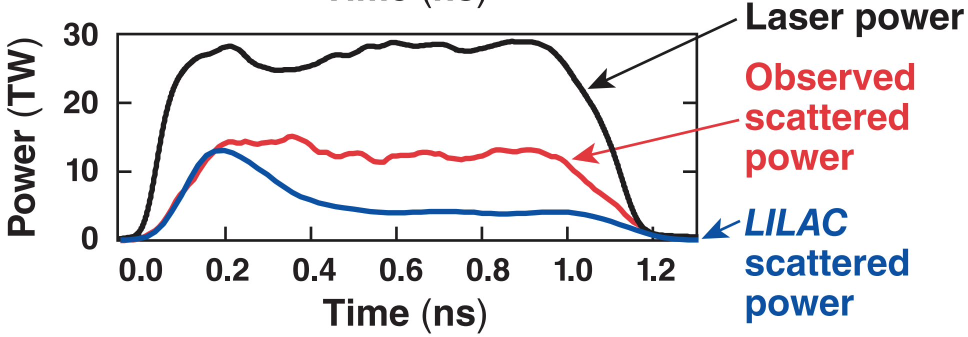
Predicted spectral shifts vary significantly with the electron-heat transport model used by hydrocode





Best match to observed spectral shifts, worst match to scattered power

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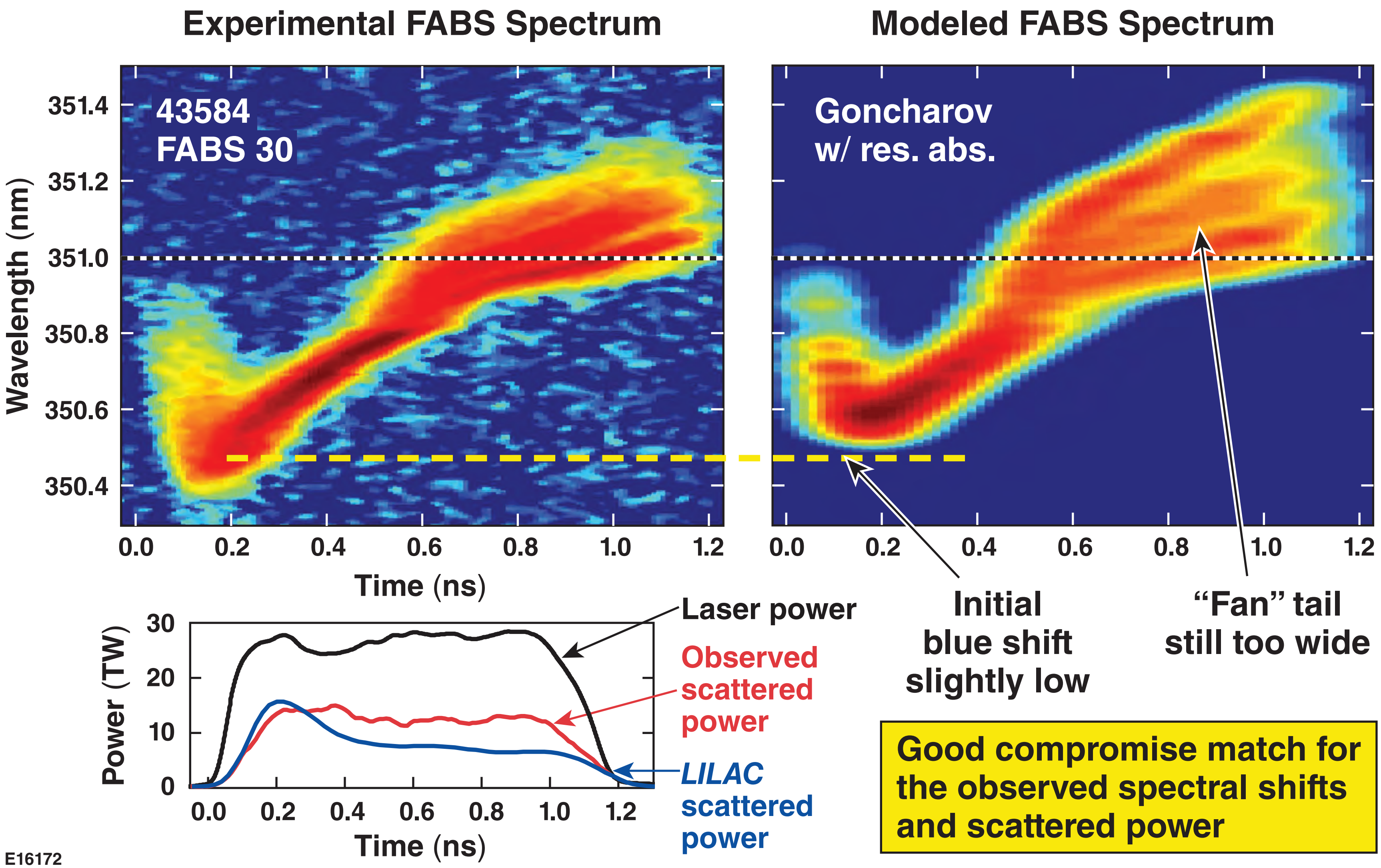
Predicted spectral shifts vary significantly with the electron-heat transport model used by hydrocode



Good compromise match for the observed spectral shifts and scattered power

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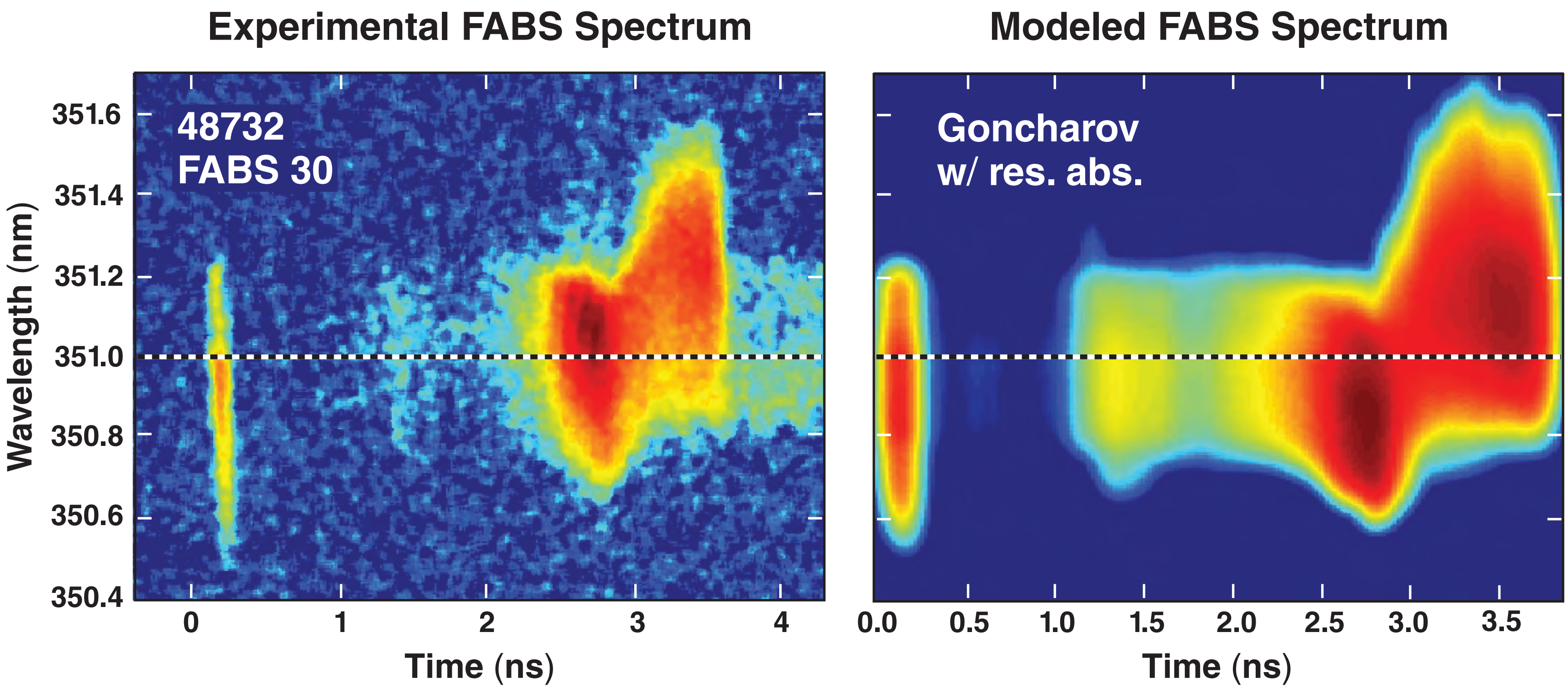
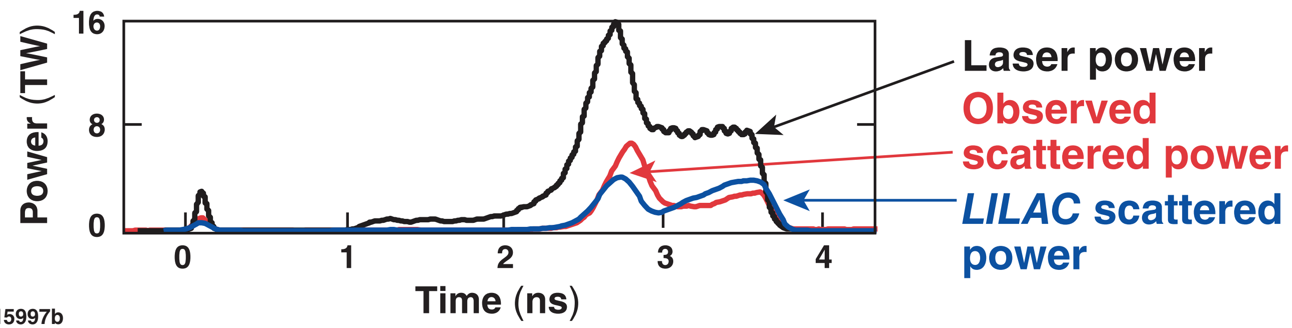
Various Other Pulse Shapes

Spectral shifts have been well modeled for a variety of pulse shapes and targets





Cryo target
SSD on

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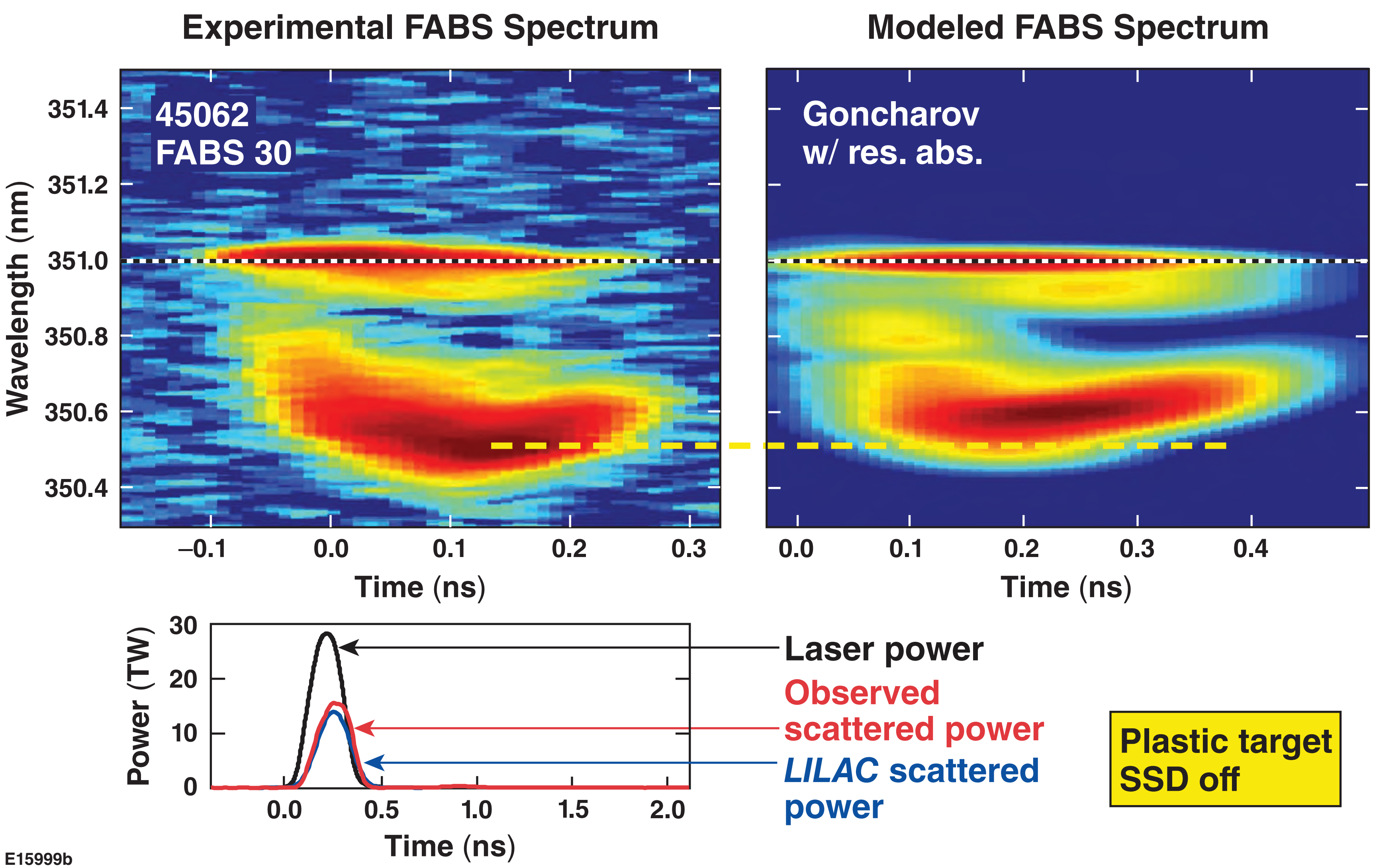
Spectral shifts have been well modeled for a variety of pulse shapes and targets



Plastic target
SSD off

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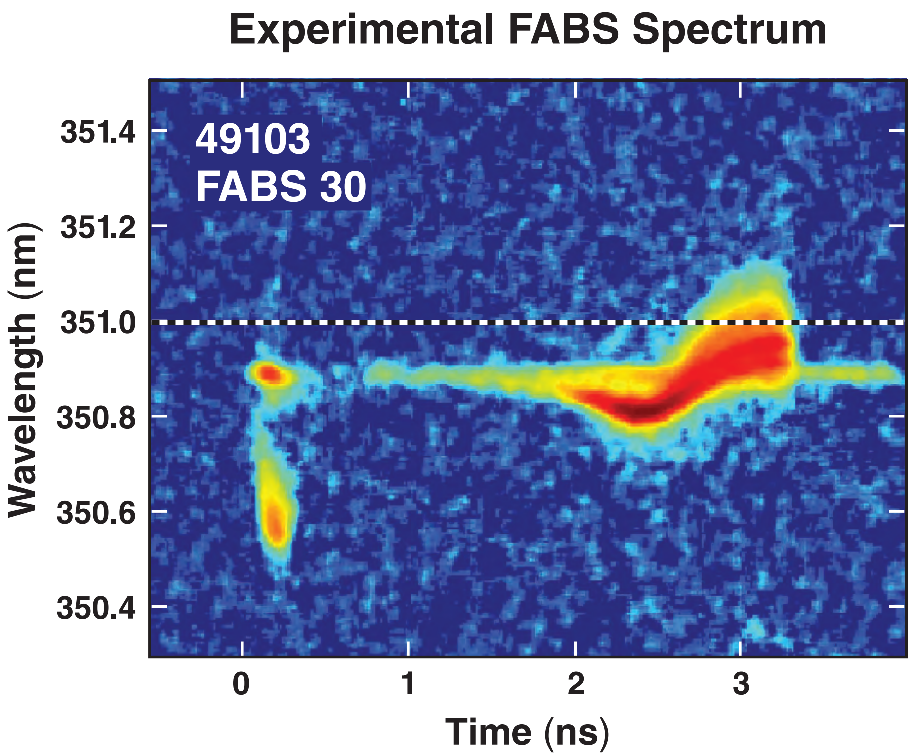
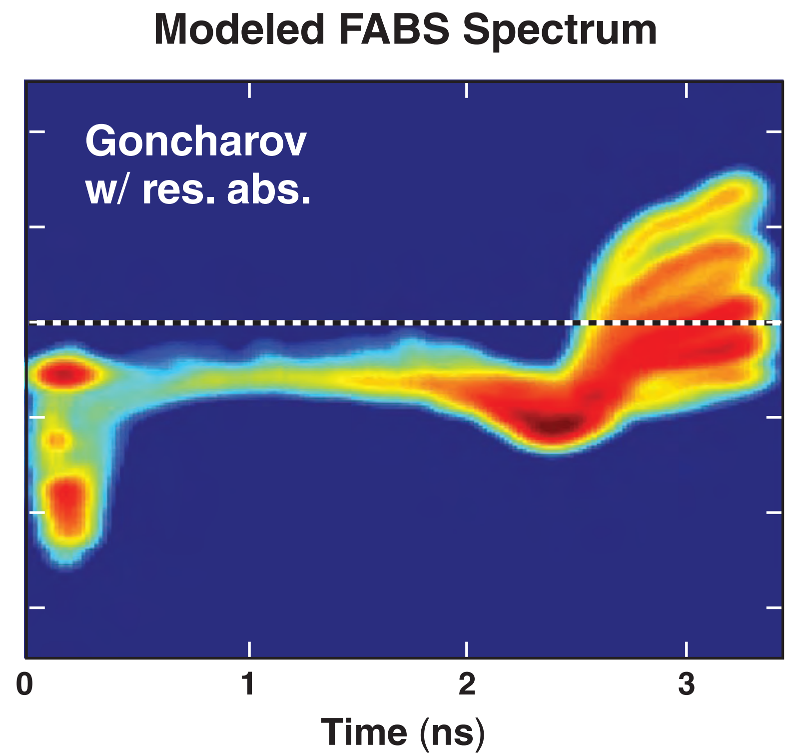
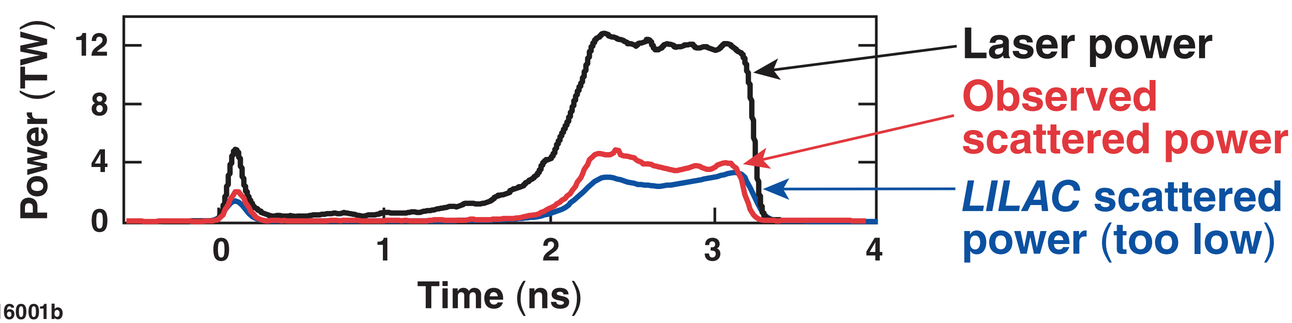
Various Other Pulse Shapes

Spectral shifts have been well modeled for a variety of pulse shapes and targets







Cryo target
SSD off

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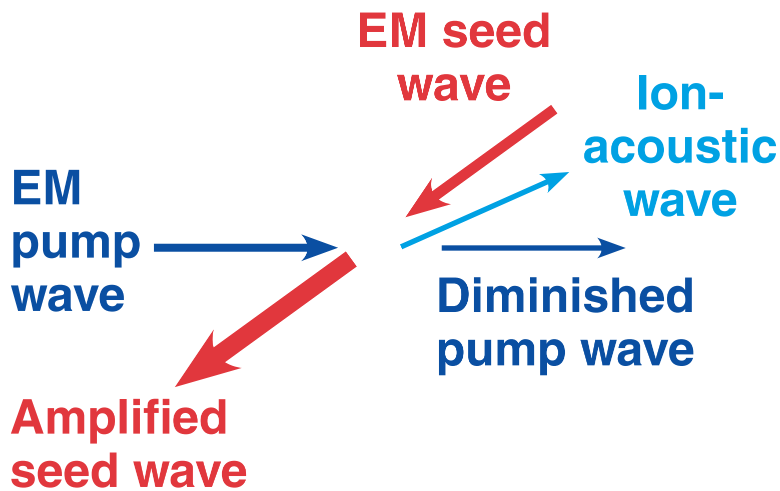
Modeling of coronal plasma is currently insufficient to predict both scattered power and spectral shifts

- Spectral shifts
  - best matched (particularly the initial strong blue shift) using the CEA nonlocal model *which is known to overestimate absorption*
- Scattered Power
  - all models predict more absorption than observed to some degree during the later part of the pulse
- Hydrocode needs additional physics to match observations
  - enhanced absorption at earliest points in pulse
  - enhanced scattering in latter points
- 2 ω_p cannot explain enhanced scattering at 351-nm

Nonlinear cross-beam power transfer may explain the differences

Cross-beam effects funnel power from shorter wavelengths to higher

- Ion-acoustic wave (IAW) transfers energy from a "pump" EM wave to a "seed" EM wave
- Early in the pulse, the light leaving the plasma is at a higher frequency (blue shifted) than the incoming laser light
  - energy could be funneled back into the target increasing absorption
- Late in the pulse, the light leaving the plasma is at a lower frequency (red shifted) than the incoming laser light
  - energy could bypass the target, increasing scattering



$$\omega_{\text{pump}} = \omega_{\text{seed}} + \omega_{\text{IAW}}$$

$$\vec{k}_{\text{pump}} = \vec{k}_{\text{seed}} + \vec{k}_{\text{IAW}}$$

$$\omega = c_s \left| k \right| + \vec{v}_f \cdot \vec{k}$$

Observed shifts *of the order of Angstroms of the order* needed to satisfy this dispersion relation

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