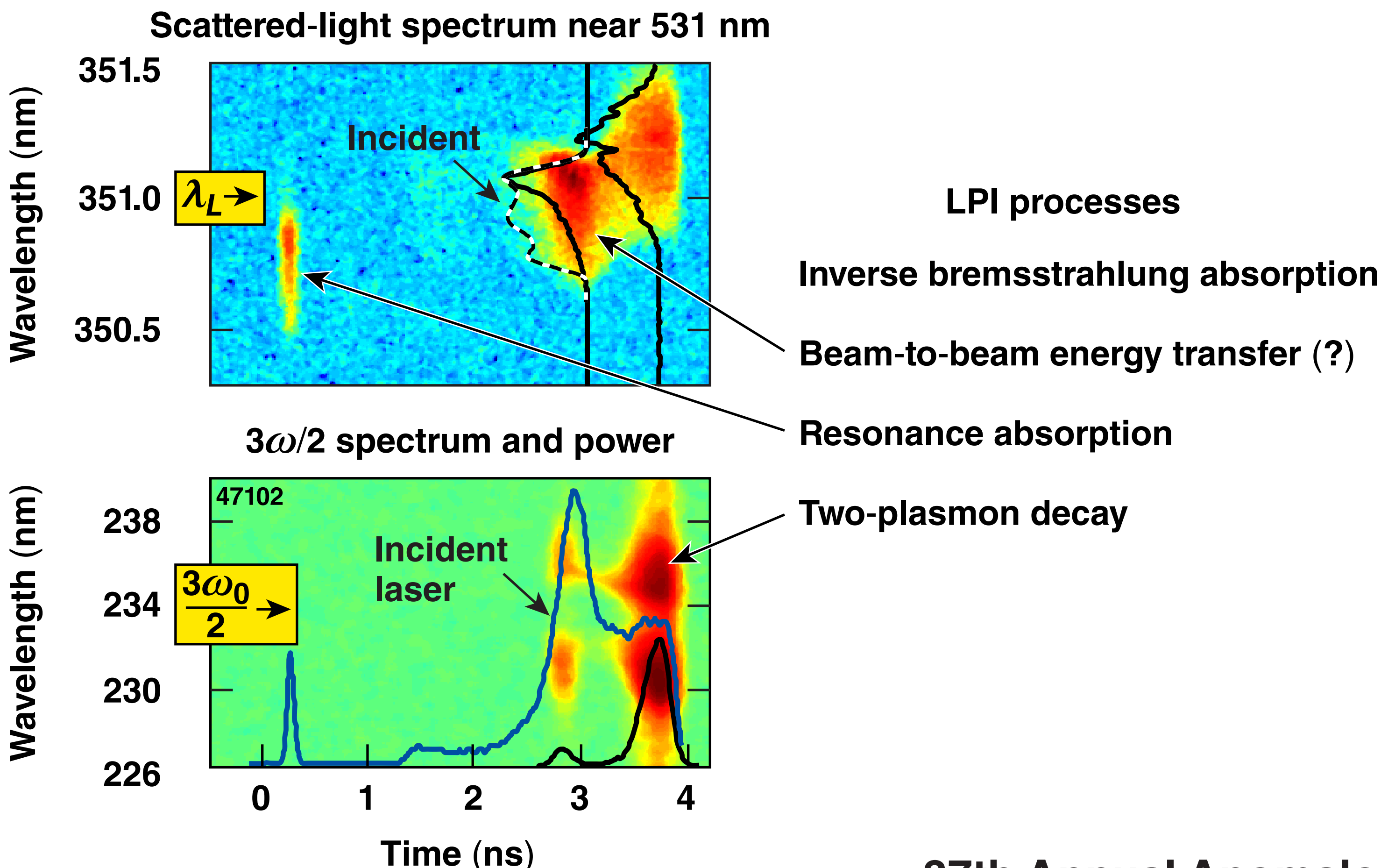
Laser–Plasma Interaction Processes Observed in Direct-Drive Implosion Experiments



W. Seka *et al.*
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Laboratory for Laser Energetics

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Summary

Direct-drive-implosion experiments show evidence for many different LPI processes that need to be accounted for in target-performance simulations

UR LLE

- The bulk of the absorption at 351-nm irradiation is due to inverse bremsstrahlung absorption.
- During the first 200 ps of irradiation, resonance absorption enhances absorption.
- At later times ($\geq$0.8 ns) enhanced scattering points toward beam-to-beam energy transfer.
- Evidence of the two-plasmon-decay instability is seen in hard-x-ray and $3\omega/2$ self-emission spectra and absorption measurements.

E15976

Collaborators

D. H. Edgell, J. P. Knauer, C. Stoeckl, V. N. Goncharov, J. A. Delettrez,
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Laboratory for Laser Energetics

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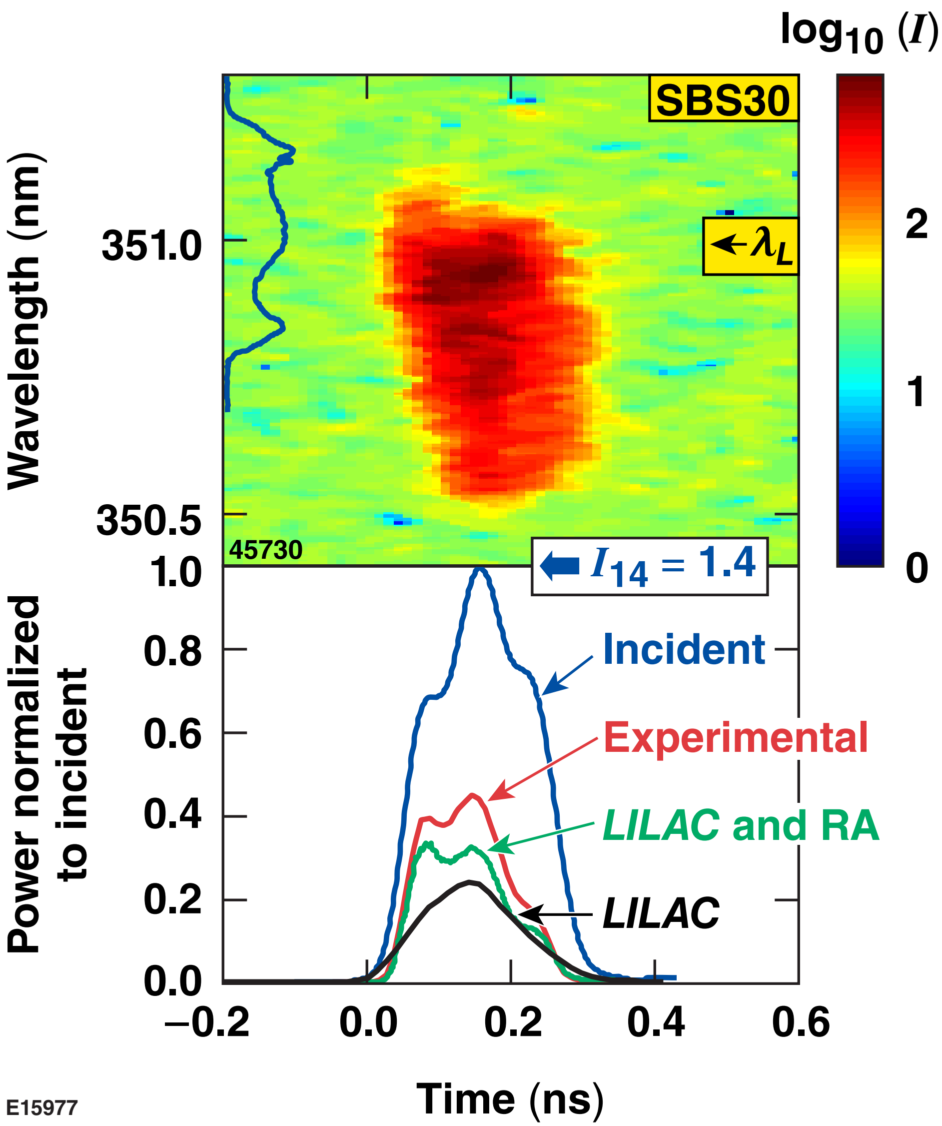
Negev, Israel

Resonance absorption is evident during the first 200 ps of irradiation

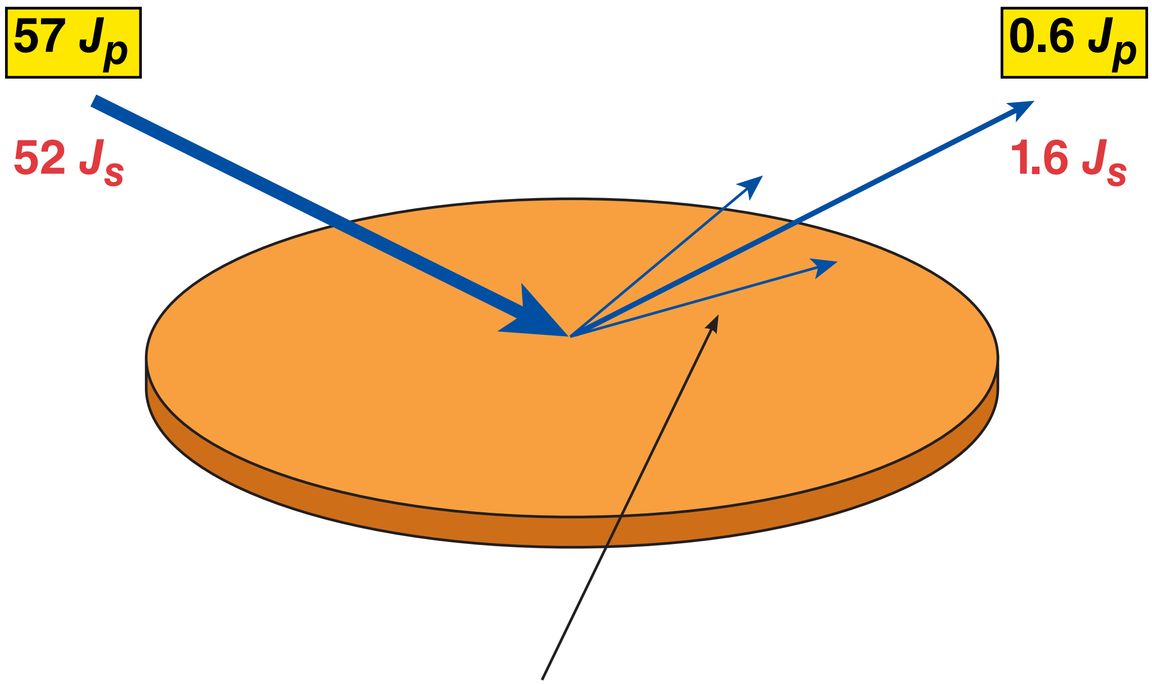
UR LLE



- CH-shell (~860-μm diam)
  - 58 beams
  - 200-ps laser pulse
  - exp. absorption: 76%
- *LILAC* prediction: IB and *f* = 0.06
  - predicted absorption: 61%
- *LILAC* with improved RA model
  - prediction: 72%

E15977

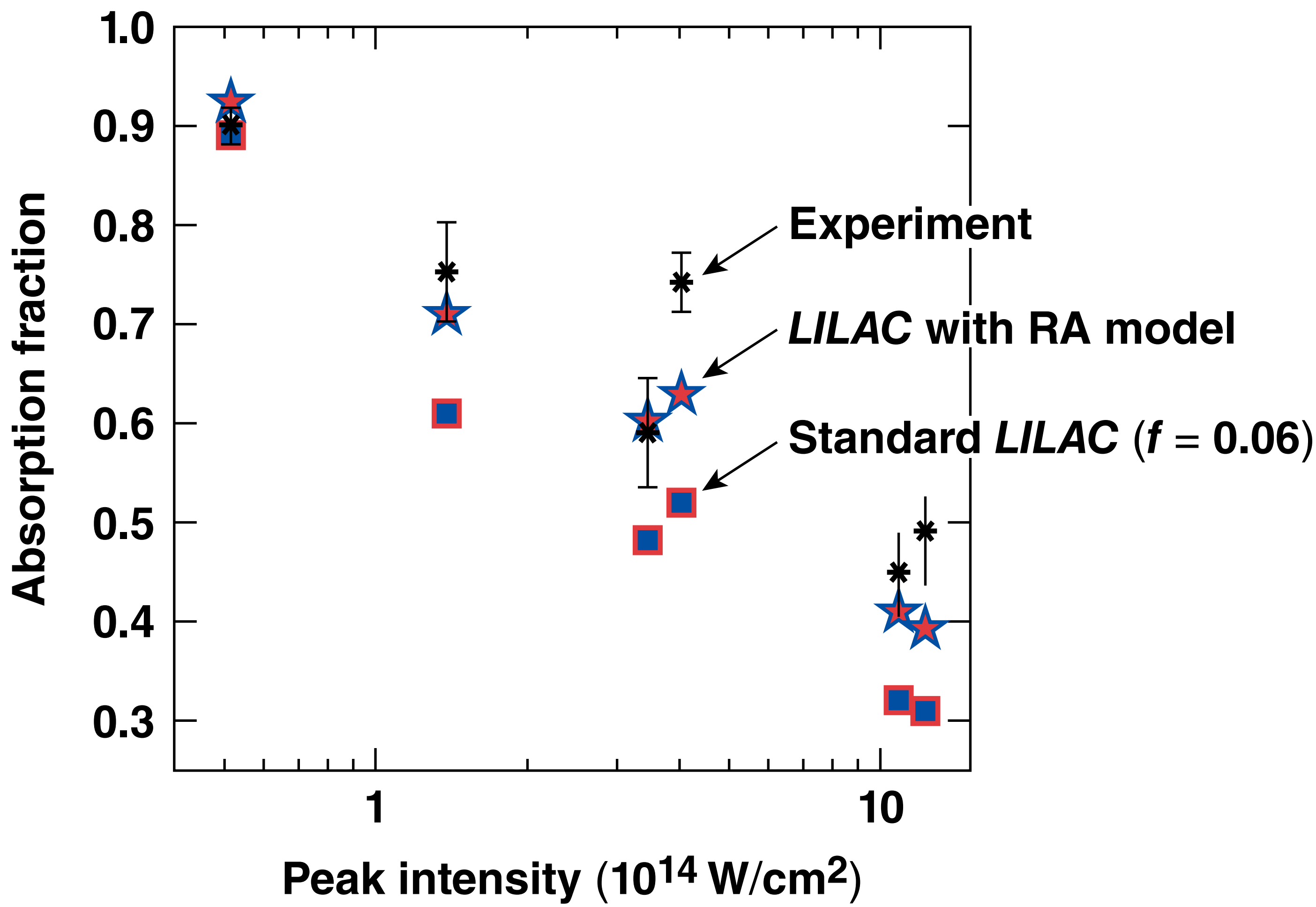
Single-beam planar-target experiments with *s* and *p* polarization support resonance-absorption hypothesis



- Light scattered outside lens cone
  - Larger than specularly reflected light (by a few times)
  - Independent of *s* or *p* polarization
  - Interpreted as rippled critical surface

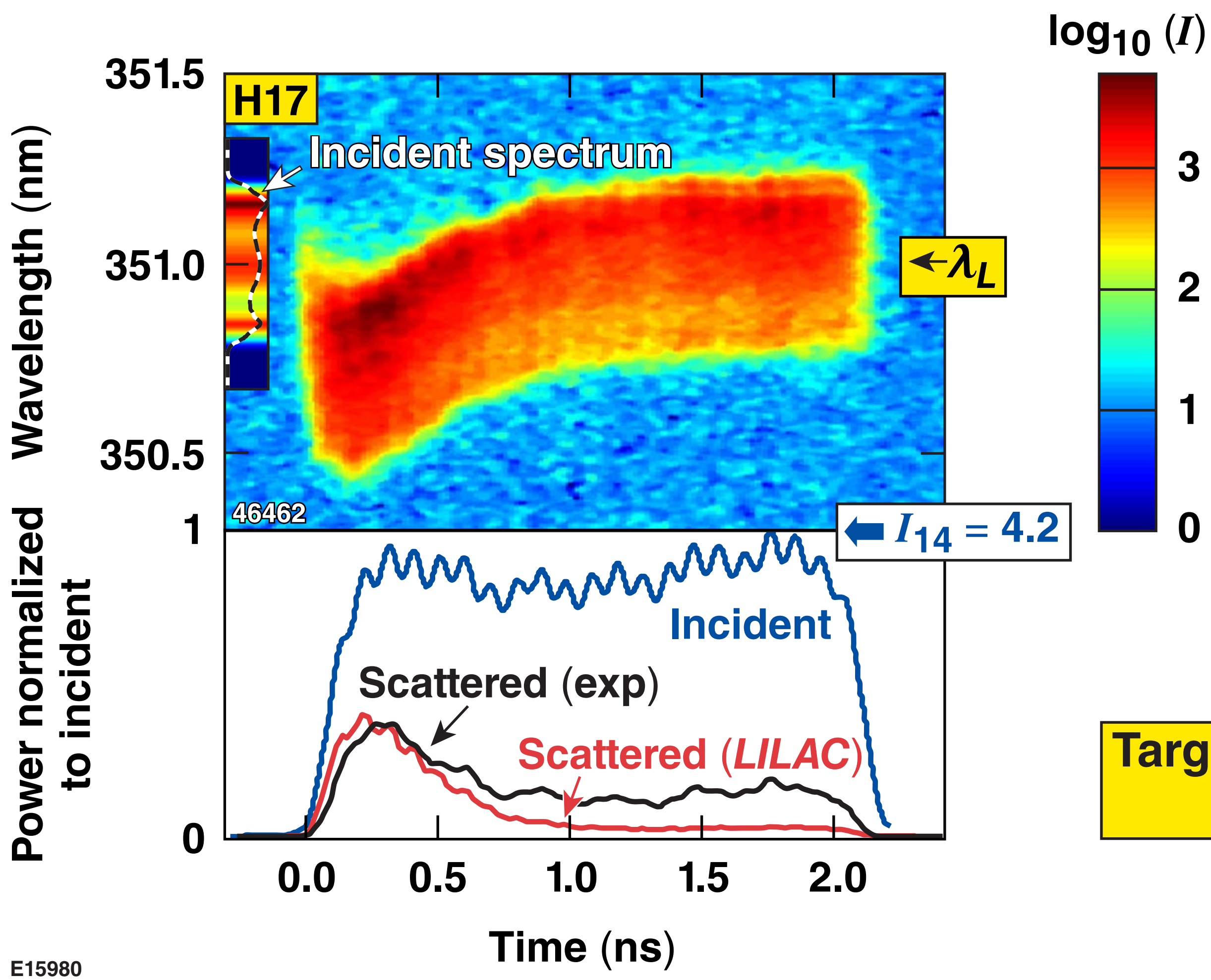
E15978

The new resonance-absorption model tracks the experimental data quite well for 200-ps irradiation



E15979

The overall spectral shifts are closely related to the coronal-plasma formation and the detailed spectral evolution indicates nonlinear LPI processes



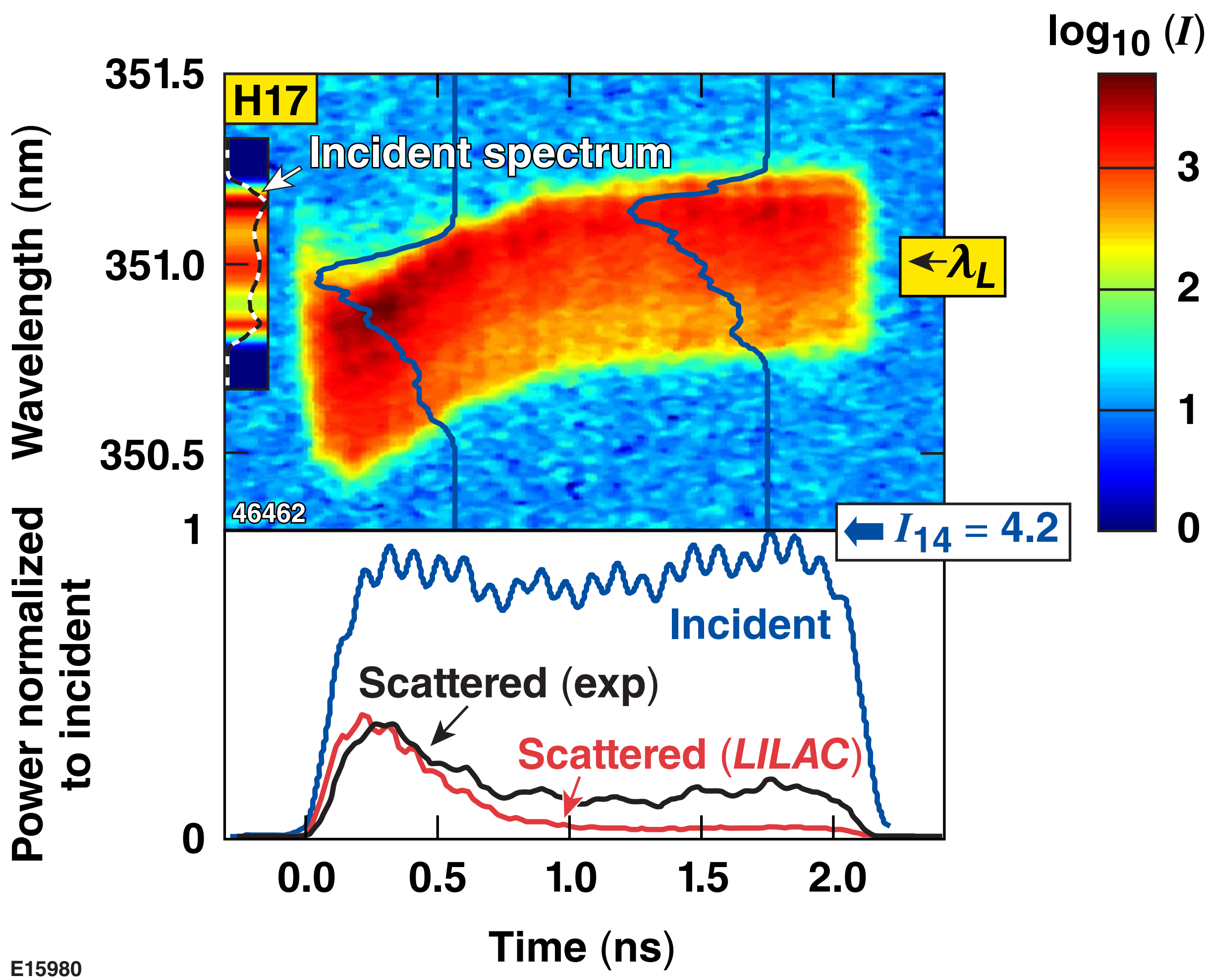
- Initial blue shift: increasing plasma column traversed by scattered light → reduced optical path length → blue shift

Target: solid-CH sphere 860-μm diam

E15980

The overall spectral shifts are closely related to the coronal-plasma formation and the detailed spectral evolution indicates nonlinear LPI processes

UR LLE



- Initial blue shift: increasing plasma column traversed by scattered light → reduced optical path length → blue shift
- Scattered light spectrum is almost always red-peaked → nonlinear process must be involved

E15980

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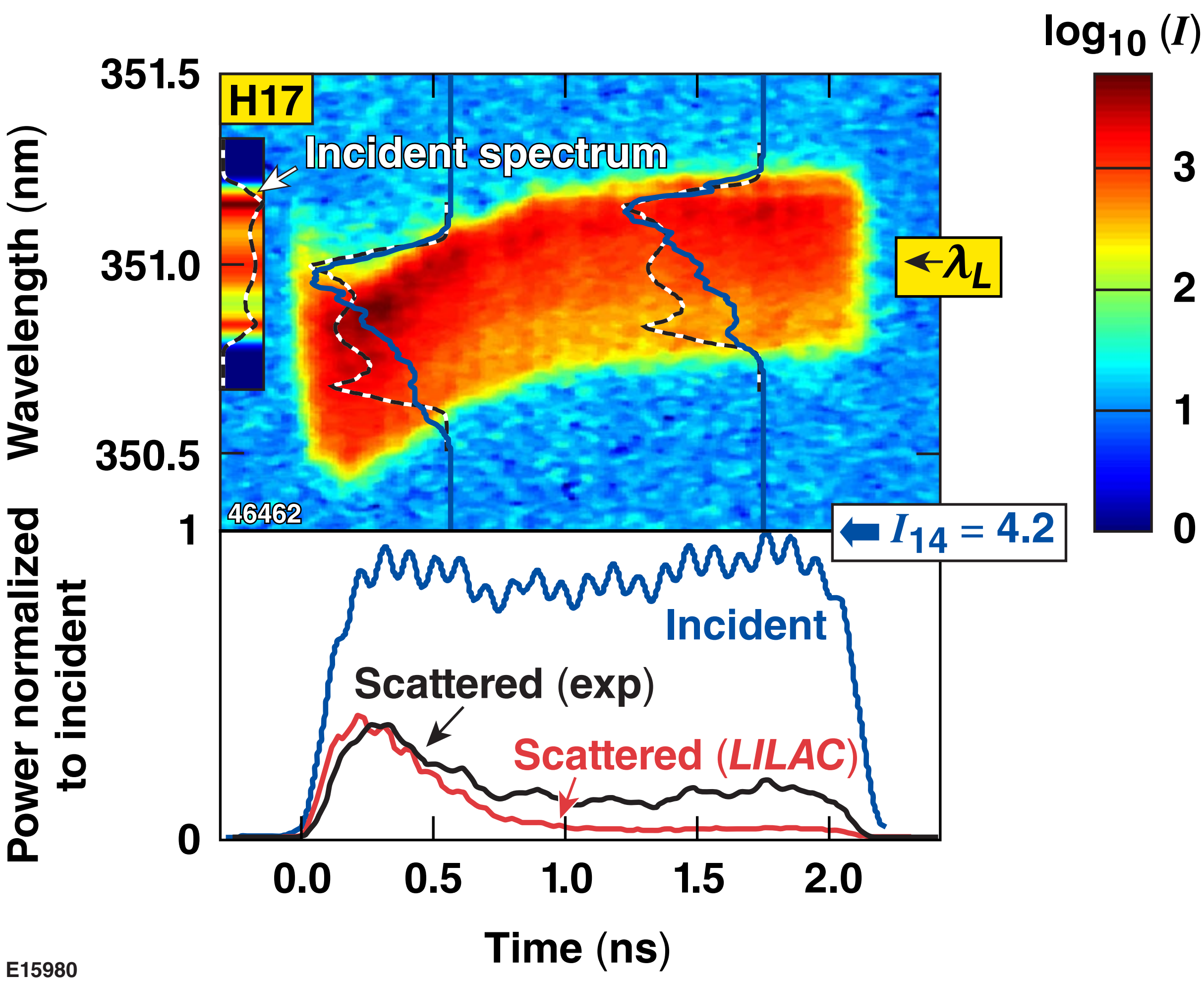

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E15980

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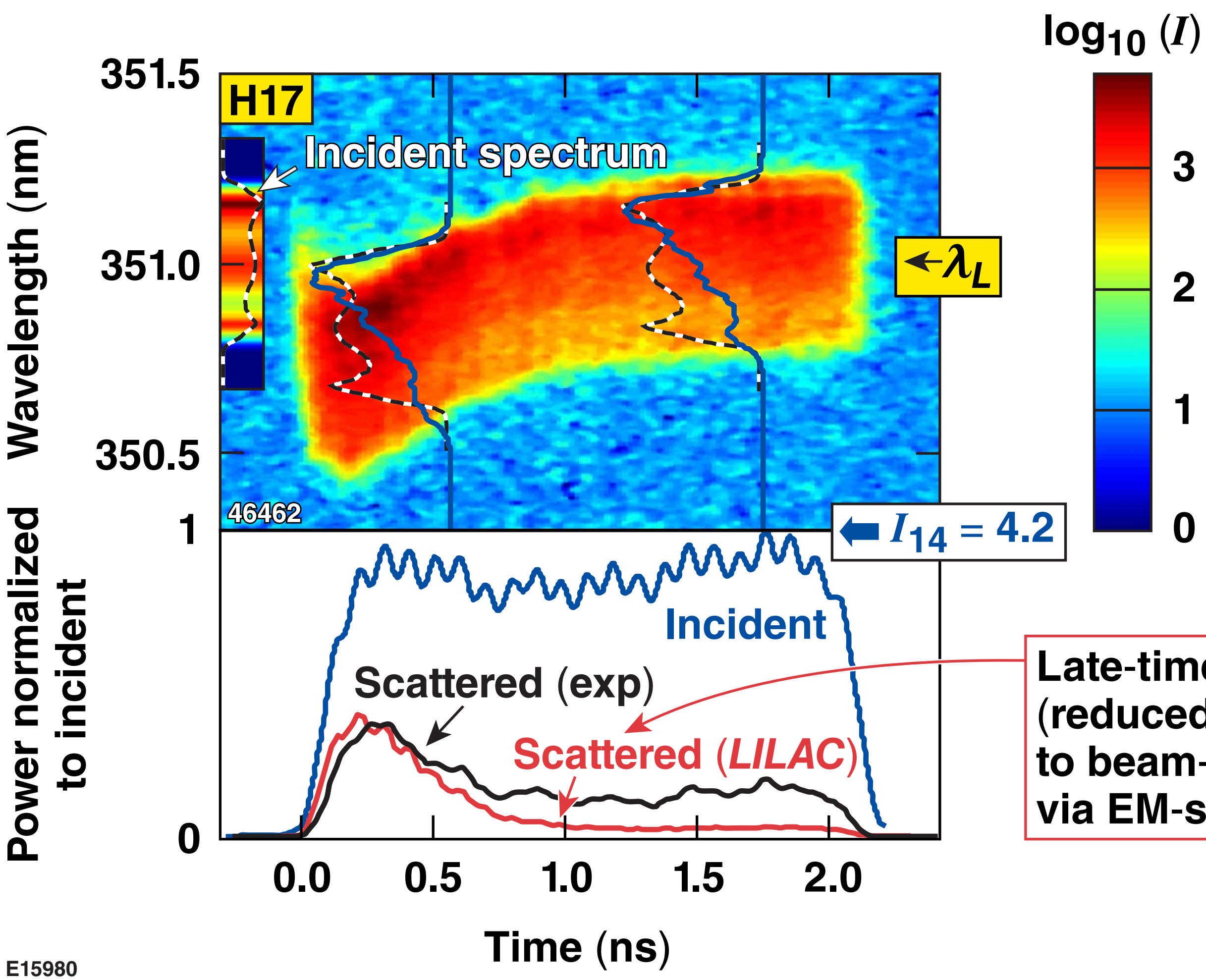
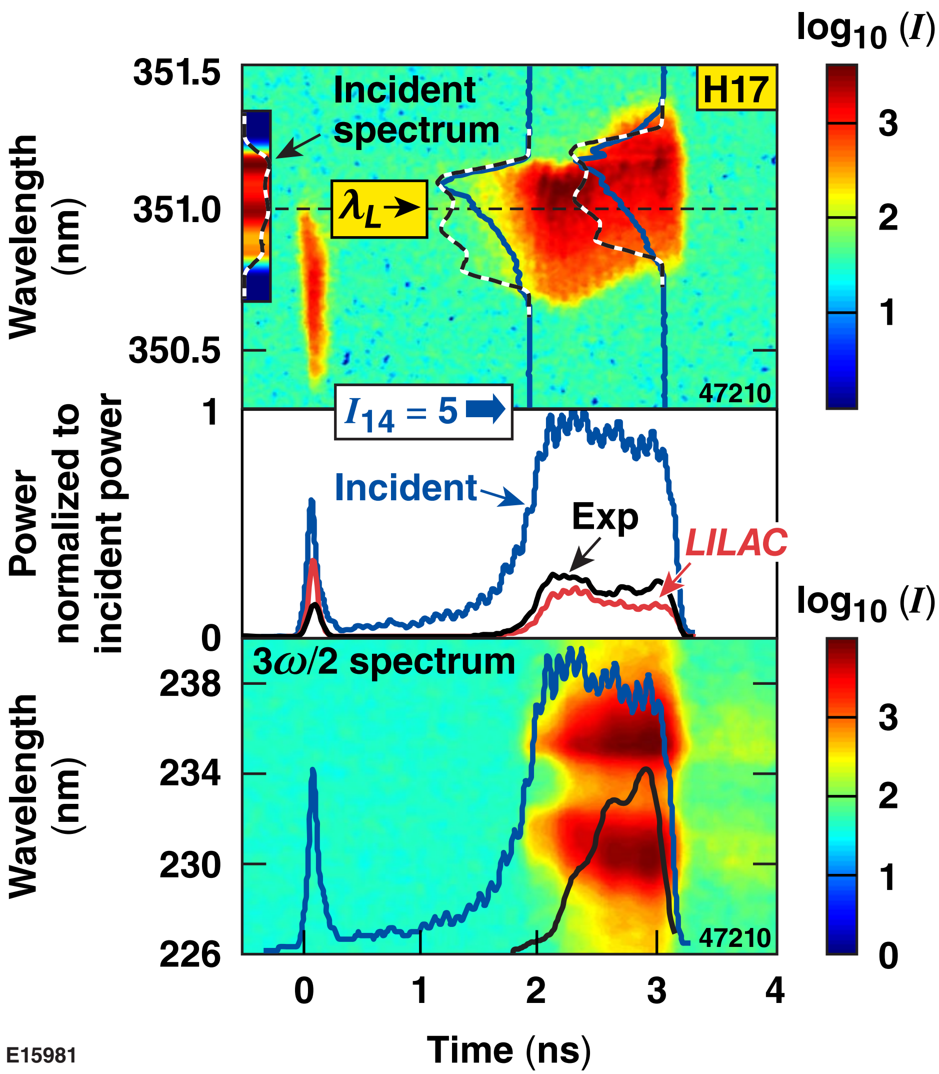


- Initial blue shift: increasing plasma column traversed by scattered light → reduced optical path length → blue shift
- Scattered light spectrum is almost always red-peaked → nonlinear process must be involved

Late-time increased scattering (reduced absorption) may be due to beam-to-beam energy transfer via EM-seeded SBS.

E15980

Resonance absorption and overall and detailed spectral features of the scattered light are observed for all pulse shapes and targets but vary in detail

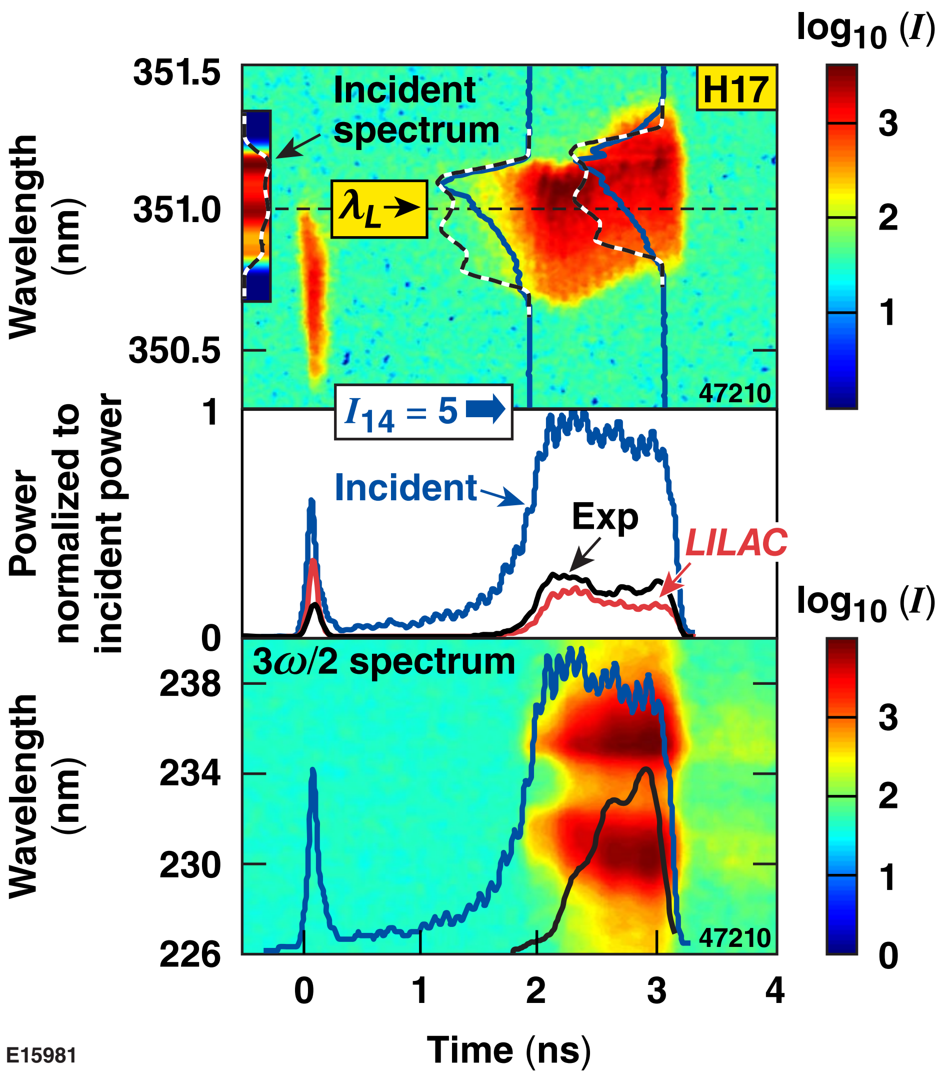


- **Overall spectral features mirror plasma evolution → modeling shows exquisite sensitivity to thermal-heat transport**
  — D. Edgell's talk
- **Two-plasmon decay signatures ($3\omega/2$ and hard-x-ray emission) seen in all direct-drive-implosion experiments**

Cryo target:
10-μm CD wall
97-μm D_2 ice
889-μm OD

E15981

Resonance absorption and overall and detailed spectral features of the scattered light are observed for all pulse shapes and targets but vary in detail

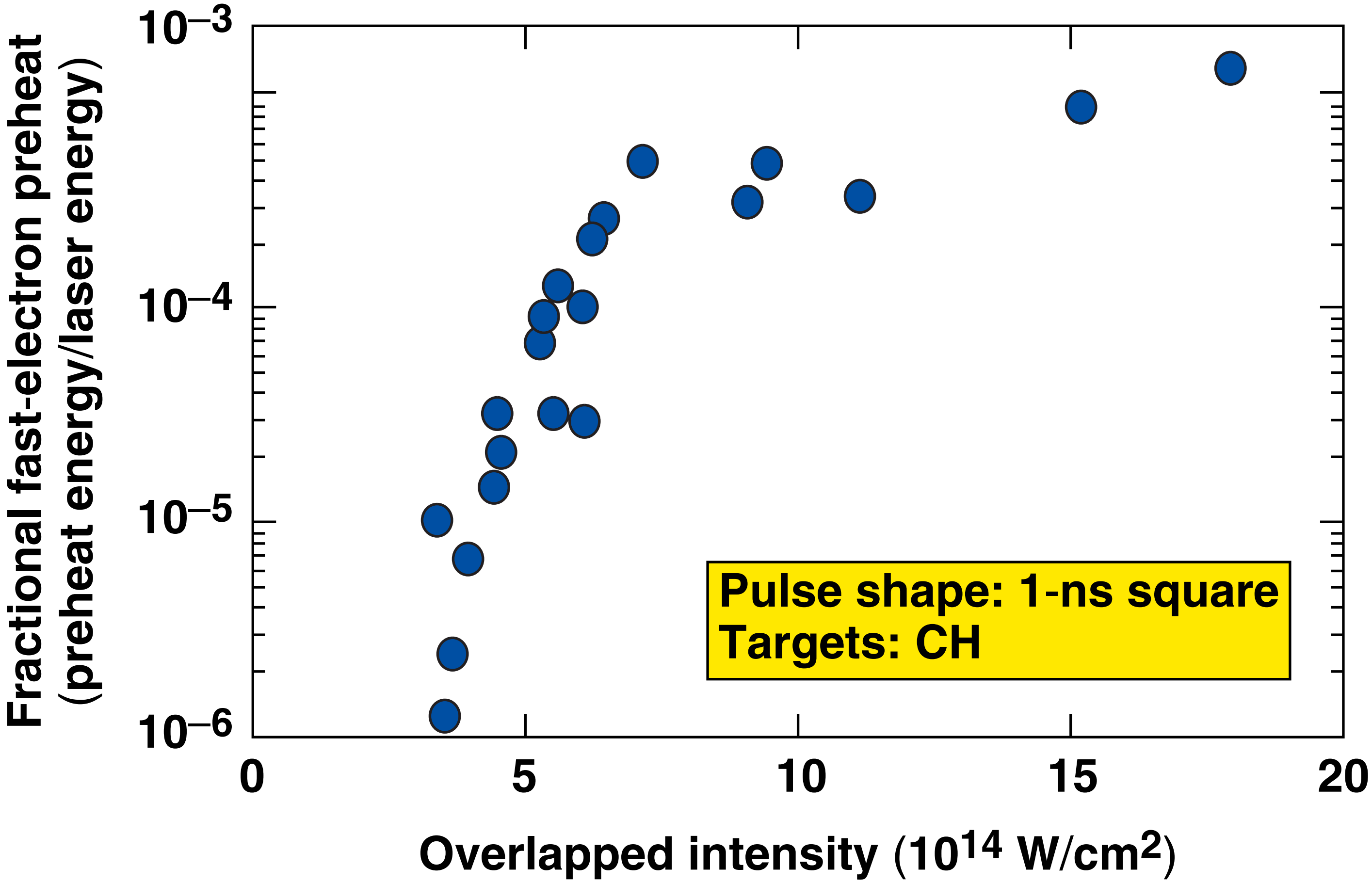


- Overall spectral features mirror plasma evolution → modeling shows exquisite sensitivity to thermal-heat transport
  — D. Edgell's talk
- Enhanced scattering compared to *LILAC* varies with pulse shape and target material
- Two-plasmon decay signatures ($3\omega/2$ and hard-x-ray emission) seen in all direct-drive-implosion experiments

Cryo target:
10-μm CD wall
97-μm D_2 ice
889-μm OD

E15981

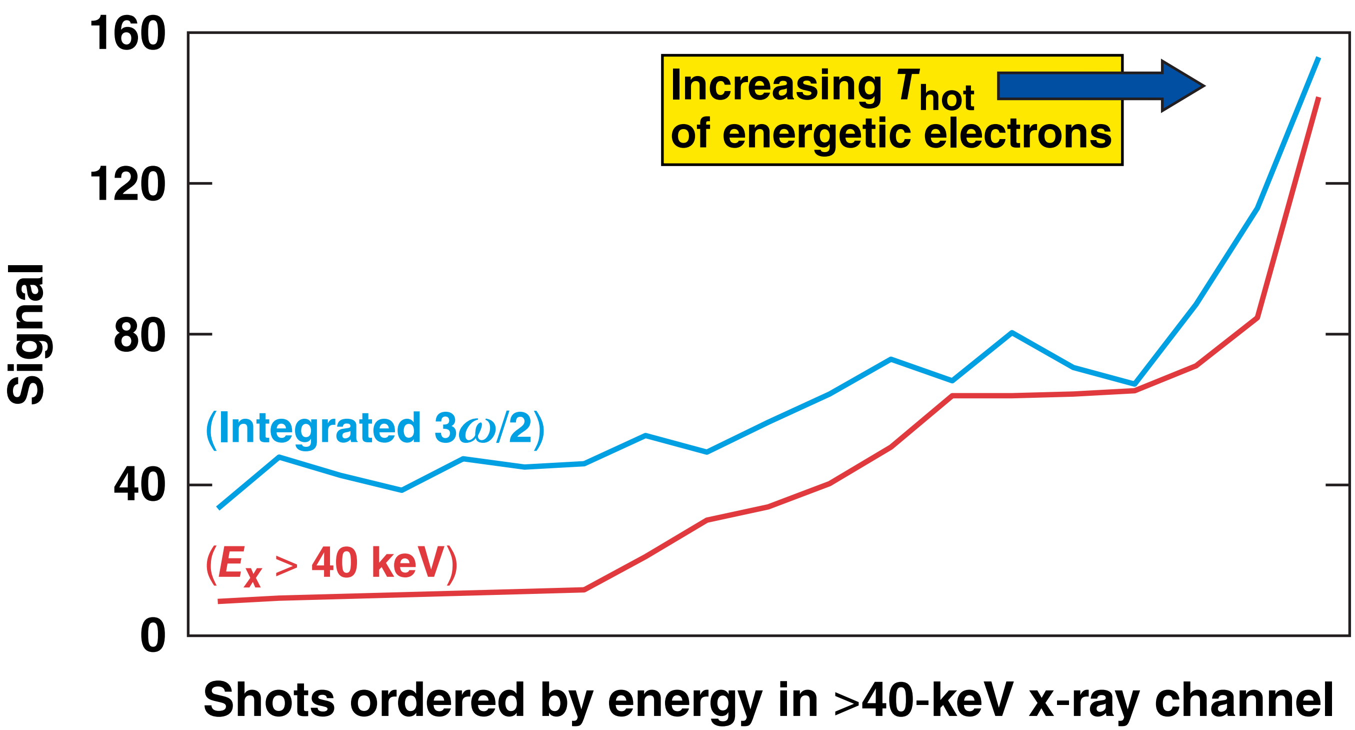
Fast-electron preheat due to TPD instability increases extremely rapidly with overlapped intensity



E15982

Hard x rays and $3\omega/2$ signals scale equally strongly with density scale length and electron temperature

Intensity on target kept constant to within 3% rms for all shots.



Targets:

- CH of various thicknesses
- some with 3-, 5-, or 10-mm Si-doped outer layer

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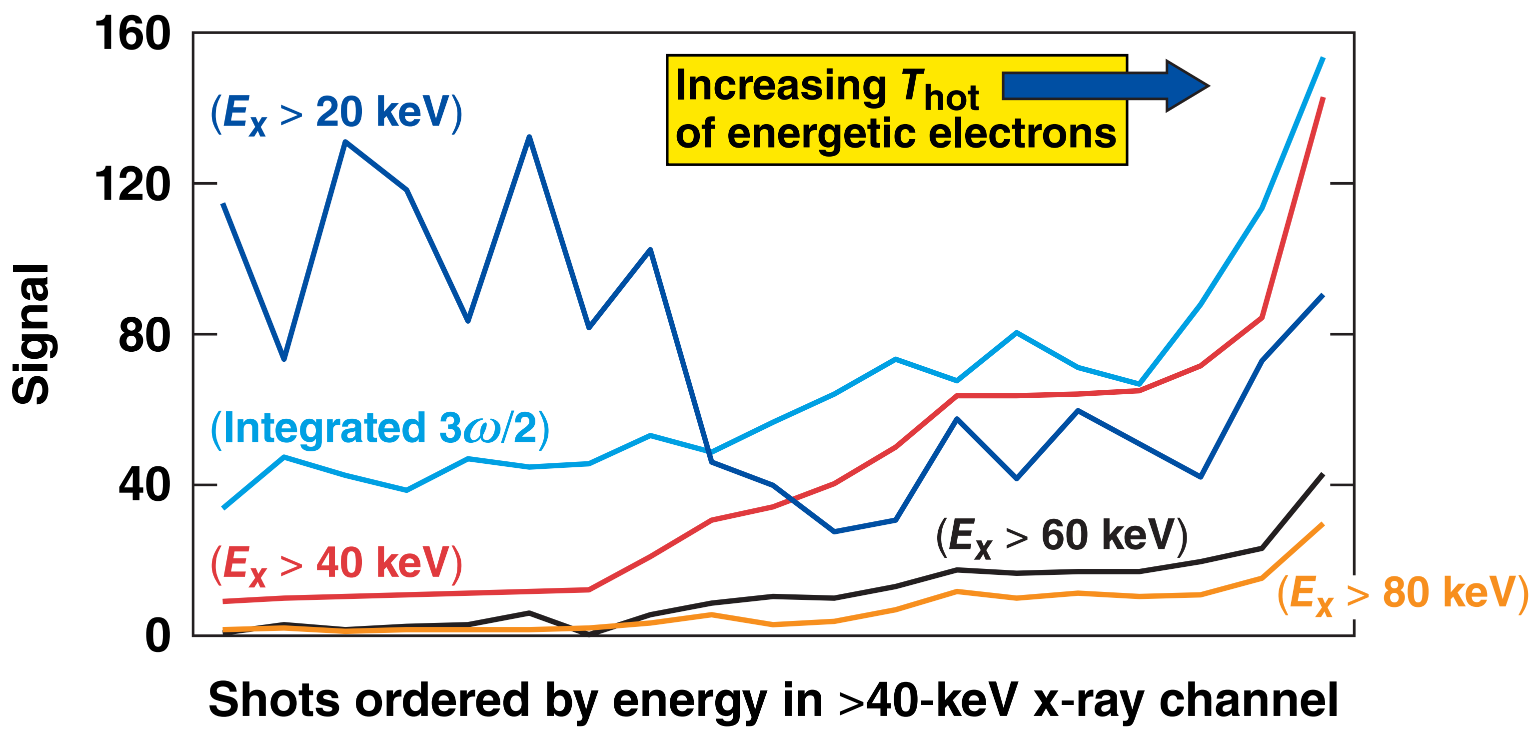
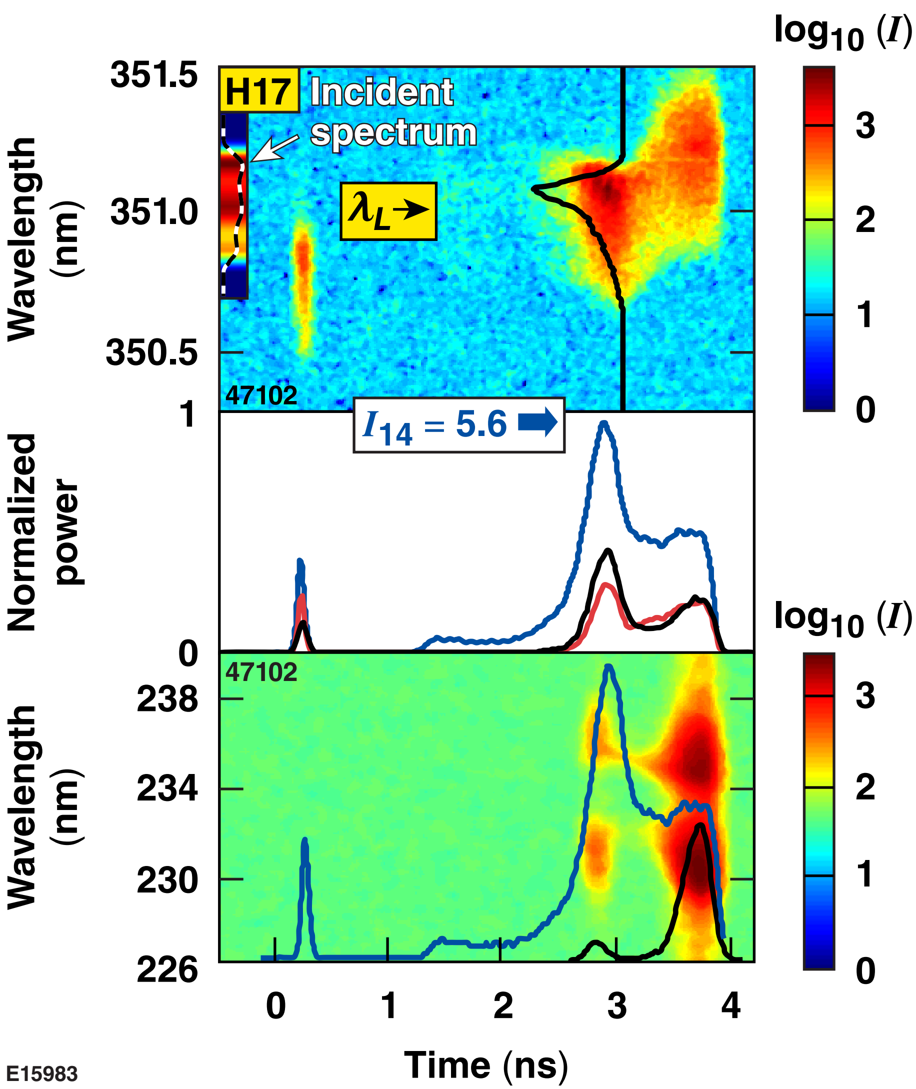


Targets:

- CH of various thicknesses
- some with 3-, 5-, or 10-mm Si-doped outer layer

E16006

Cryogenic target implosions with thin CD shells show striking features in scattered light and $3\omega/2$ spectra

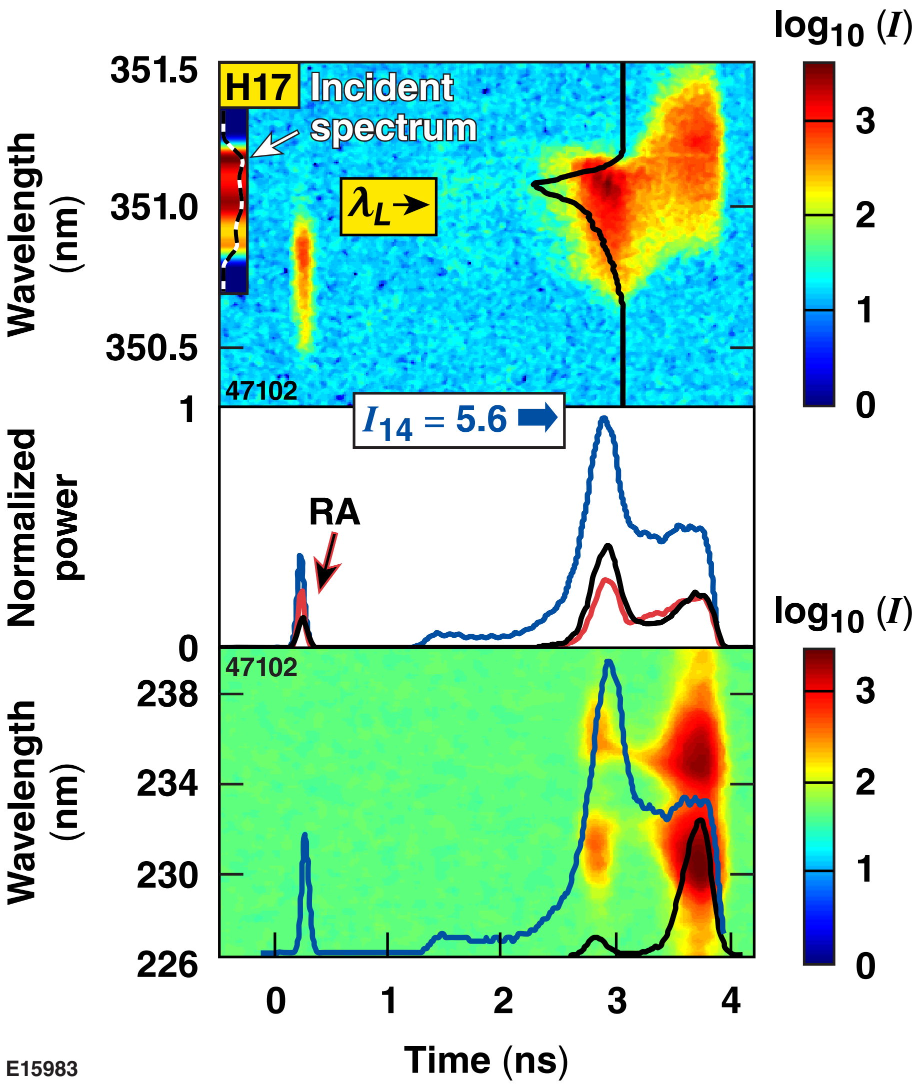


- The general scattered-light features change after the laser burns through the CD shell.

Cryo target:
4.5-μm CD wall
95-μm D_2 ice
864-μm OD

E15983

Cryogenic target implosions with thin CD shells show striking features in scattered light and 3ω/2 spectra



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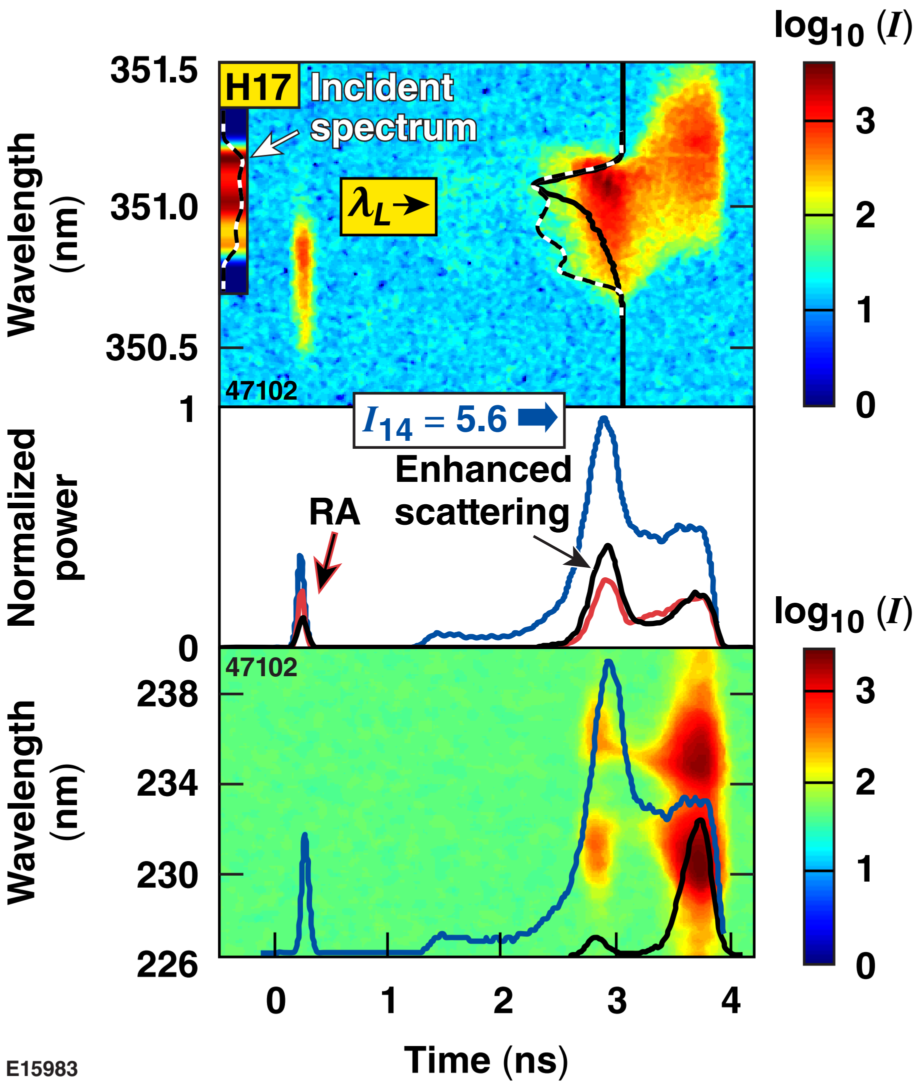

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E15983

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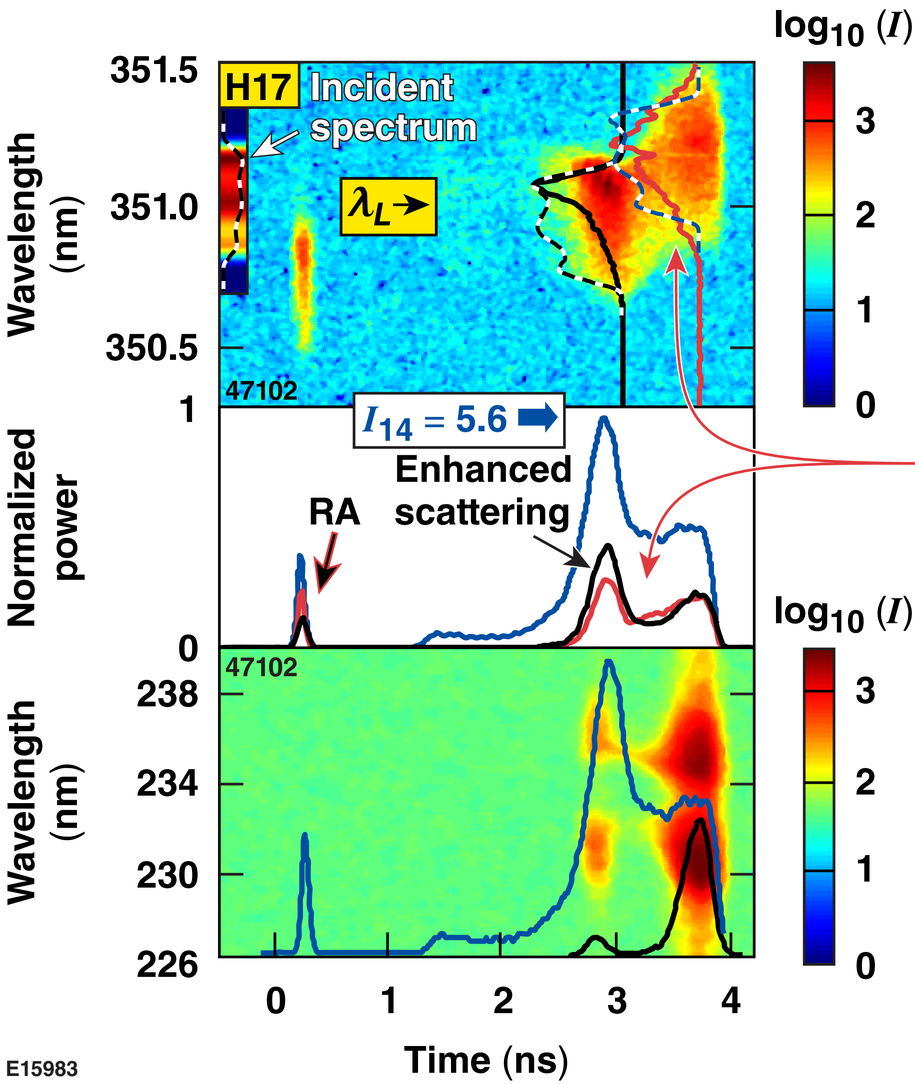

- The general scattered-light features change after the laser burns through the CD shell.

After burnthrough
- the scattered light is reduced
- the spectrum changes shape

Cryo target:
4.5-μm CD wall
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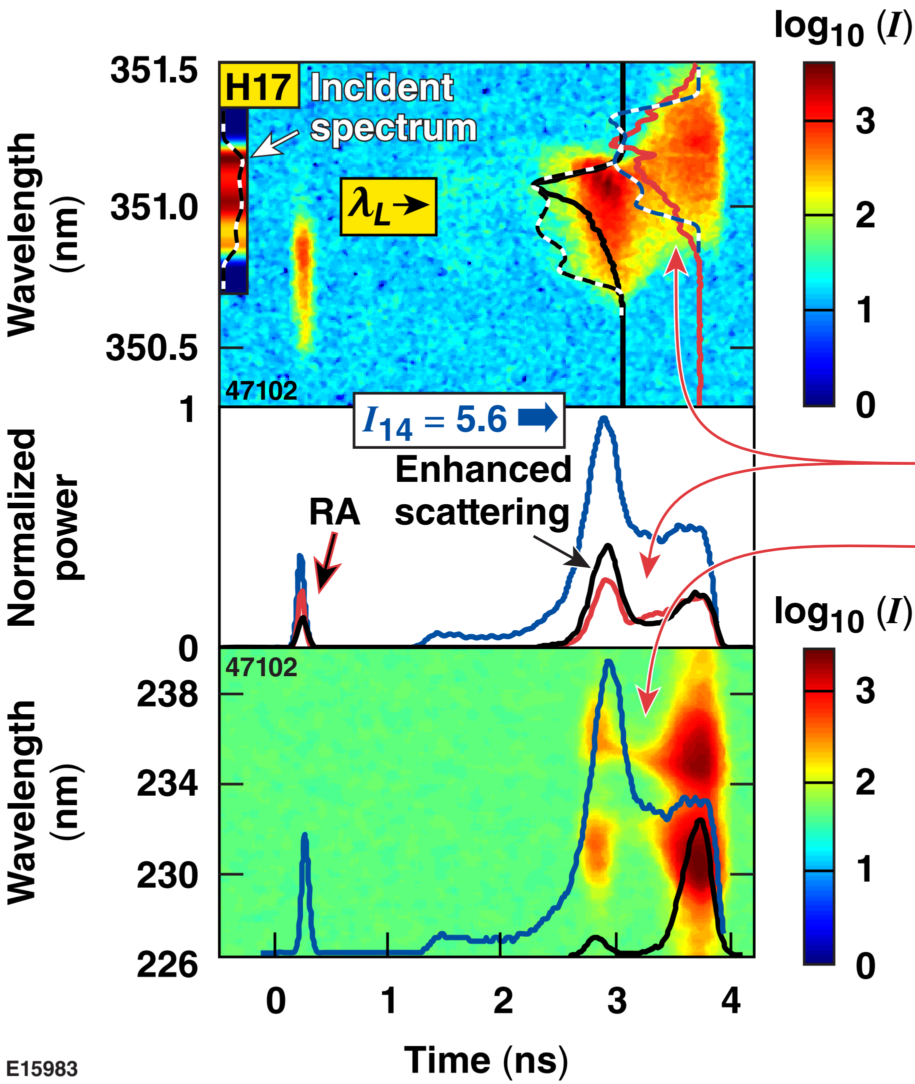
E15983

Cryogenic target implosions with thin CD shells show striking features in scattered light and $3\omega/2$ spectra



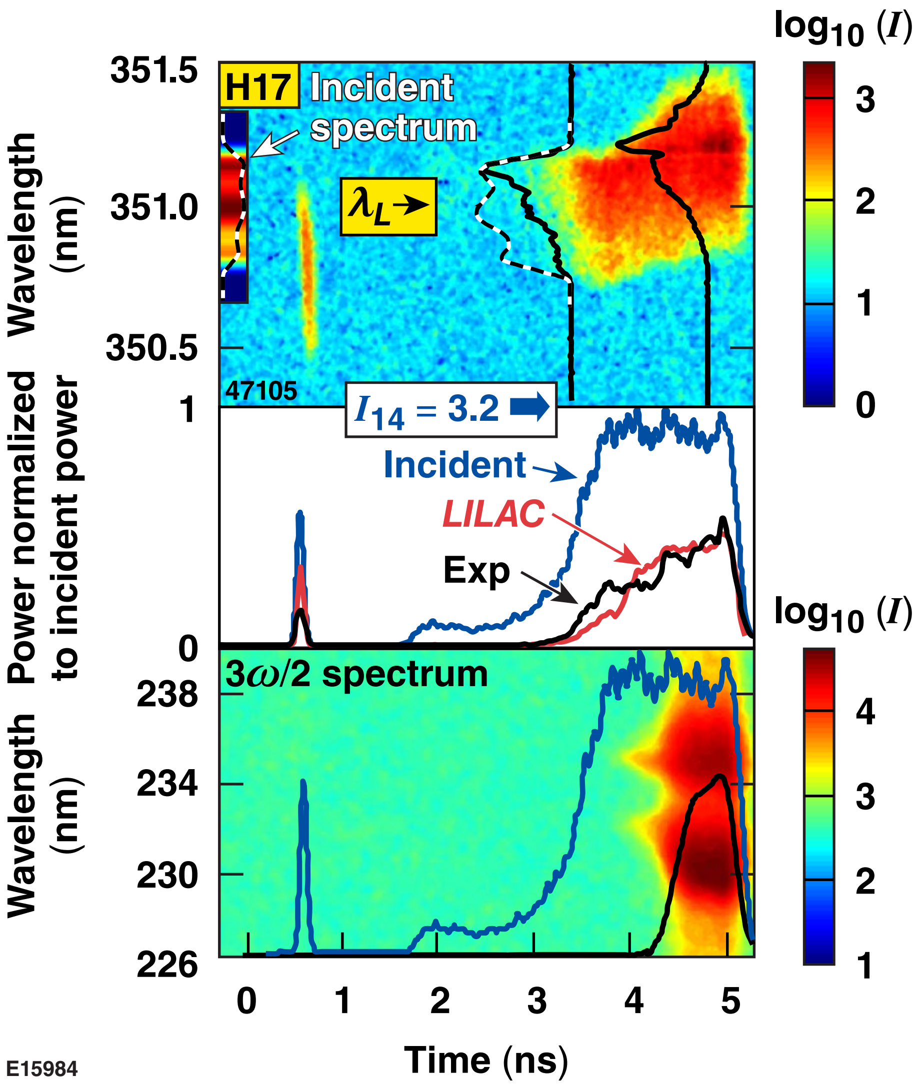
- The general scattered-light features change after the laser burns through the CD shell.

After burnthrough
- the scattered light is reduced
- the spectrum changes shape
- $3\omega/2$ emission increases significantly in spite of reduced intensity

Cryo target:
4.5-μm CD wall
95-μm D_2 ice
864-μm OD

E15983

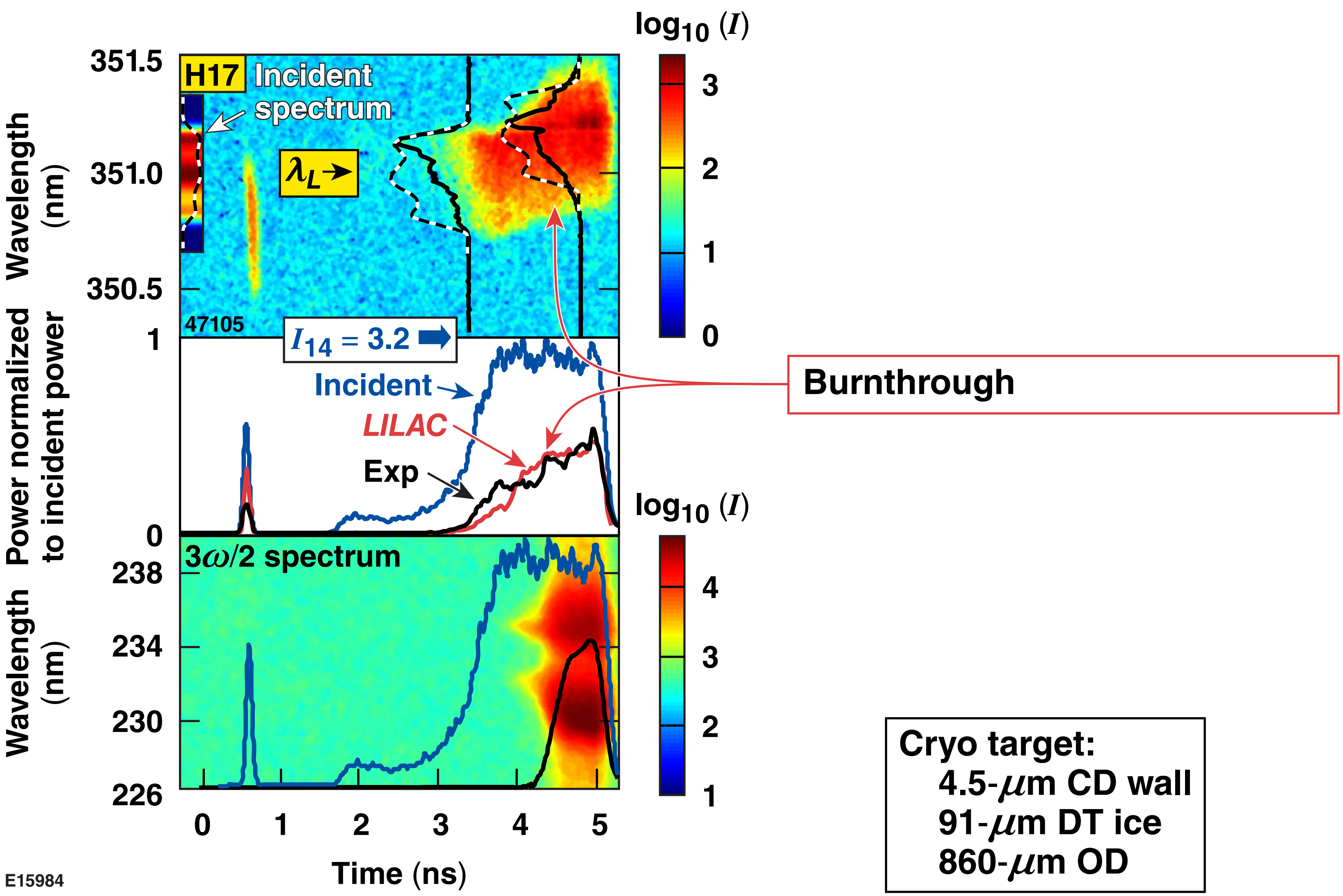
The TPD instability ($3\omega/2$ emission) is very sensitive to both T_e and density-gradient length



E15984

Cryo target:
4.5-μm CD wall
91-μm DT ice
860-μm OD

The TPD instability ($3\omega/2$ emission) is very sensitive to both T_e and density-gradient length



Cryo target:
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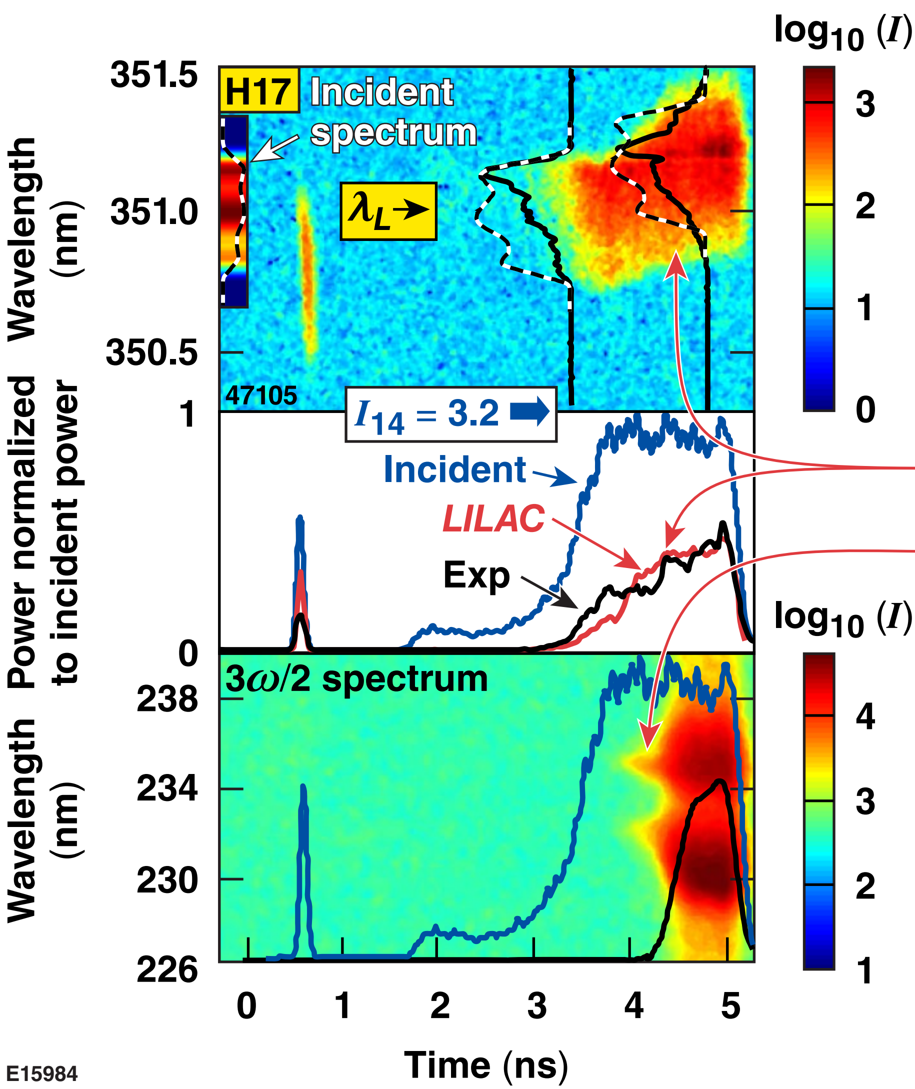
- 91-μm DT ice
- 860-μm OD

E15984

The TPD instability ($3\omega/2$ emission) is very sensitive to both T_e and density-gradient length



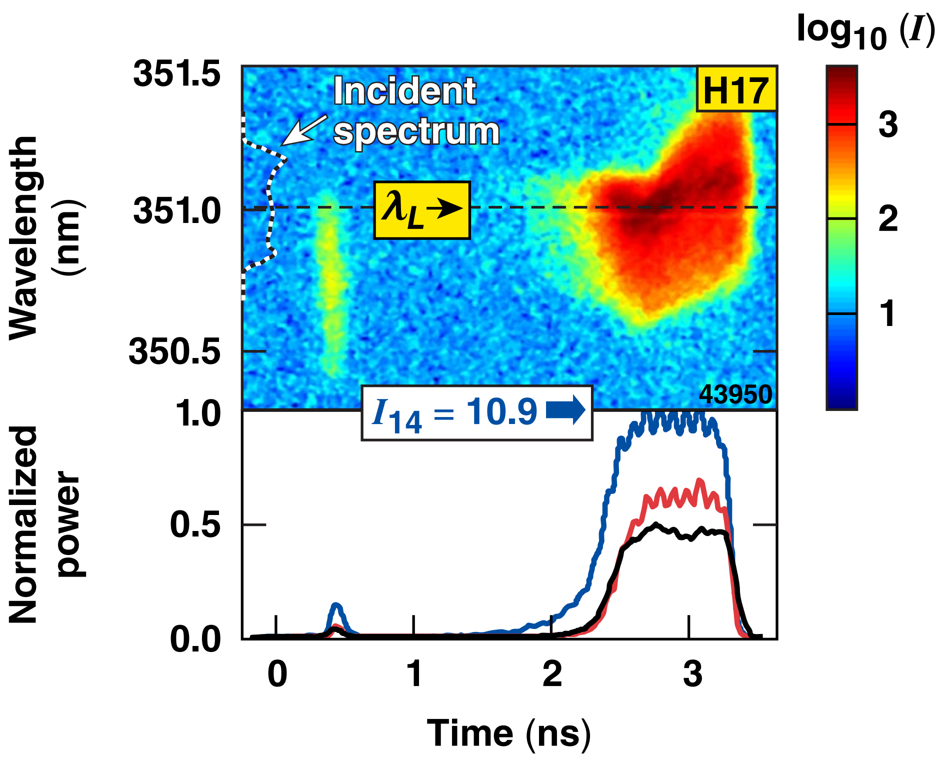
Burnthrough

- $3\omega/2$ emission even stronger than in preceding shot
- lower peak intensity
- $\rightarrow T_e$ slightly lower

Cryo target:
4.5-μm CD wall
91-μm DT ice
860-μm OD

E15984

High-intensity, cryogenic target implosions with thin DH shells produce copious amounts of fast electrons due to TPD instability and the effect is seen in absorption



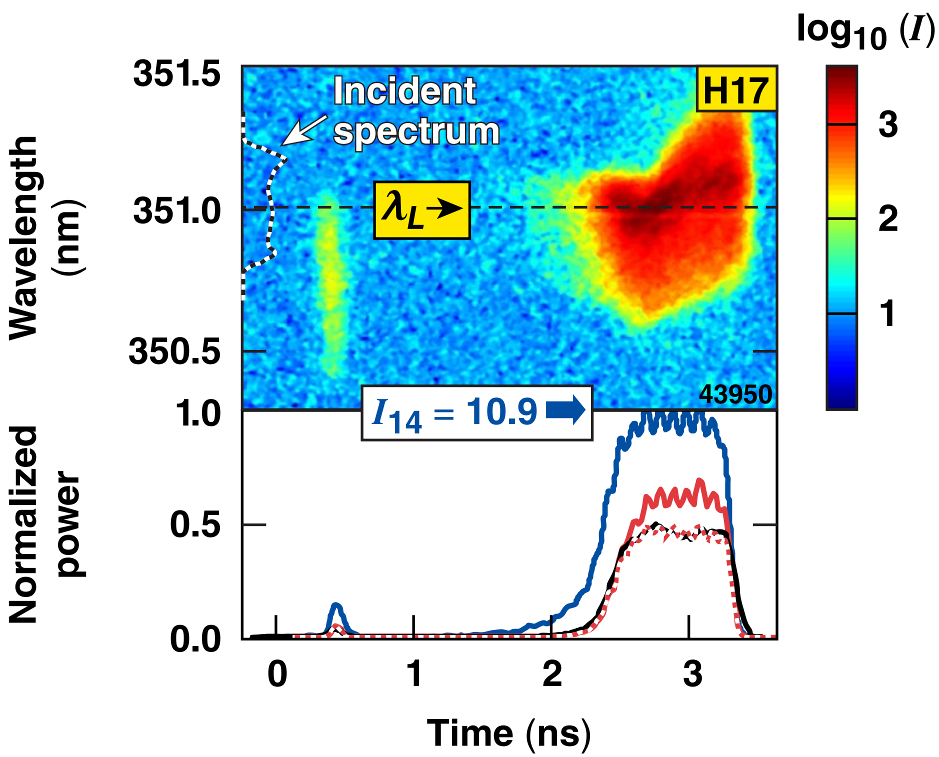
For more info, see talks by

- J. A. Delettrez (Tuesday)
- D. Shvarts (Wednesday)

Cryo target:
3.6-μm CD wall
95-μm D_2 ice
858-μm OD

E16026

High-intensity, cryogenic target implosions with thin DH shells produce copious amounts of fast electrons due to TPD instability and the effect is seen in absorption



Cryo target:
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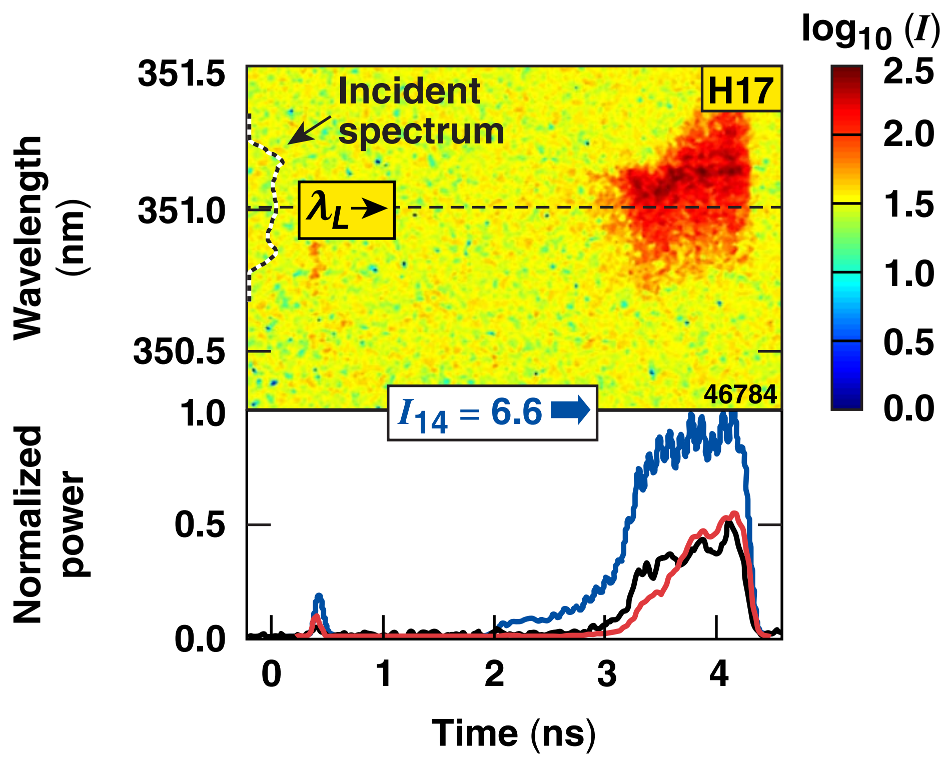
Ad hoc LILAC model for TPD results in agreement with

- ρR degradation due to preheat
- hard-x-ray signals
- threshold scaling ~ I Ln/T_e
- dump at n_c/4 into energetic electrons (rapidly increasing, saturating at 30%)

E16026

At lower intensity, the *ad hoc* TPD "dump model" still predicts total absorption very well



Cryo target:
5-μm CD wall
95-μm D_2 ice
863-μm OD

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Ad hoc LILAC **model for TPD results in agreement with**

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E16027

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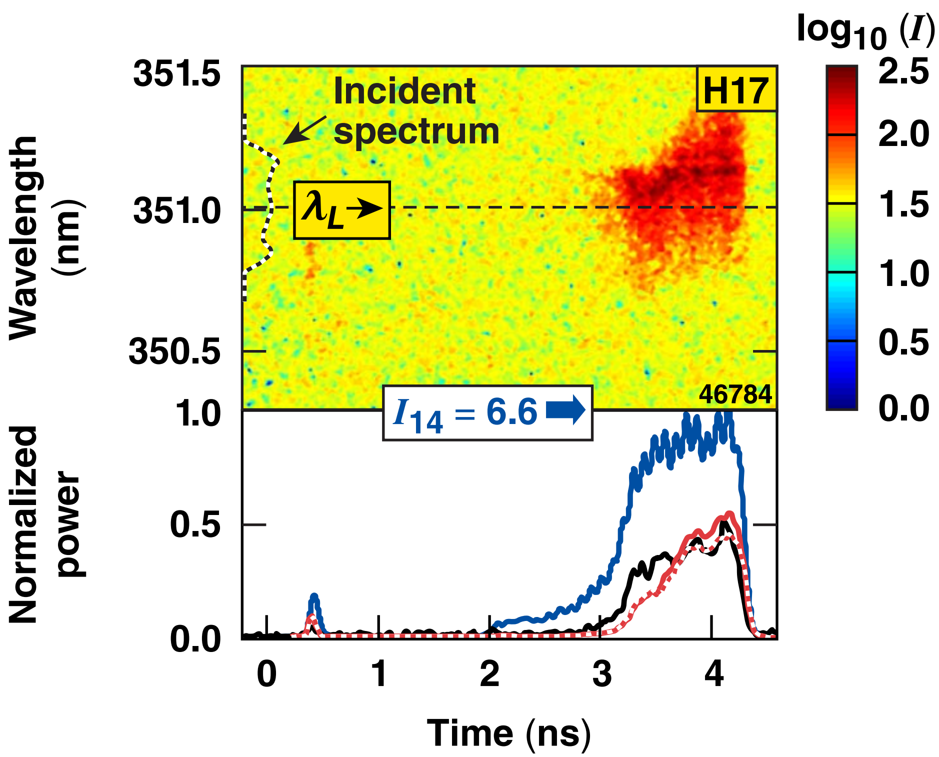

Cryo target:
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- 95-μm D_2 ice
- 863-μm OD

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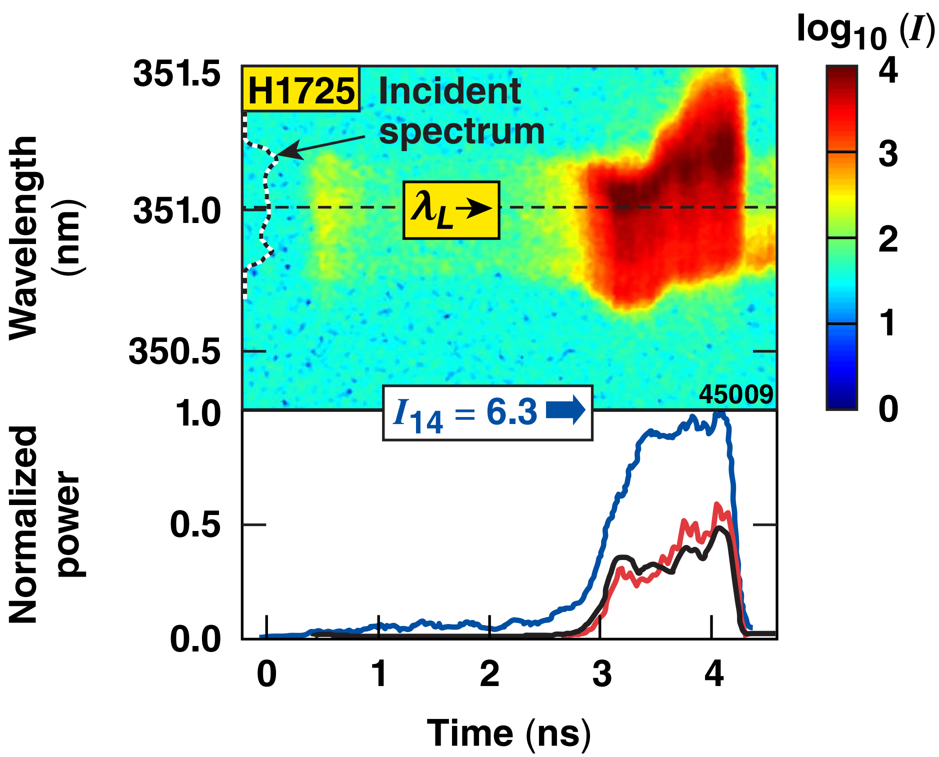

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E16028

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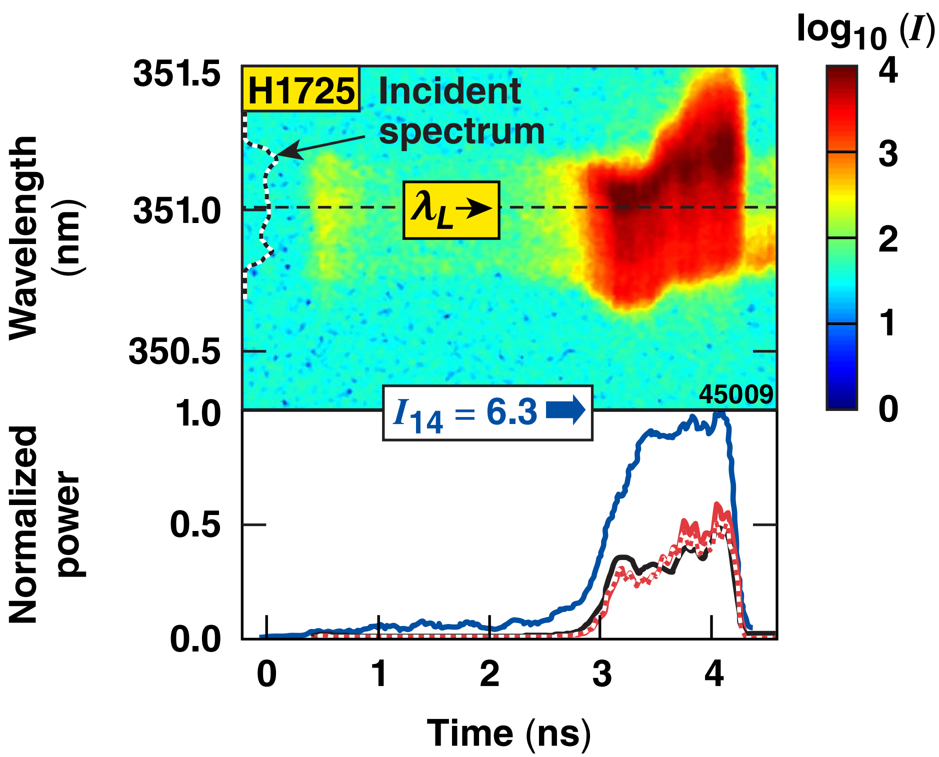

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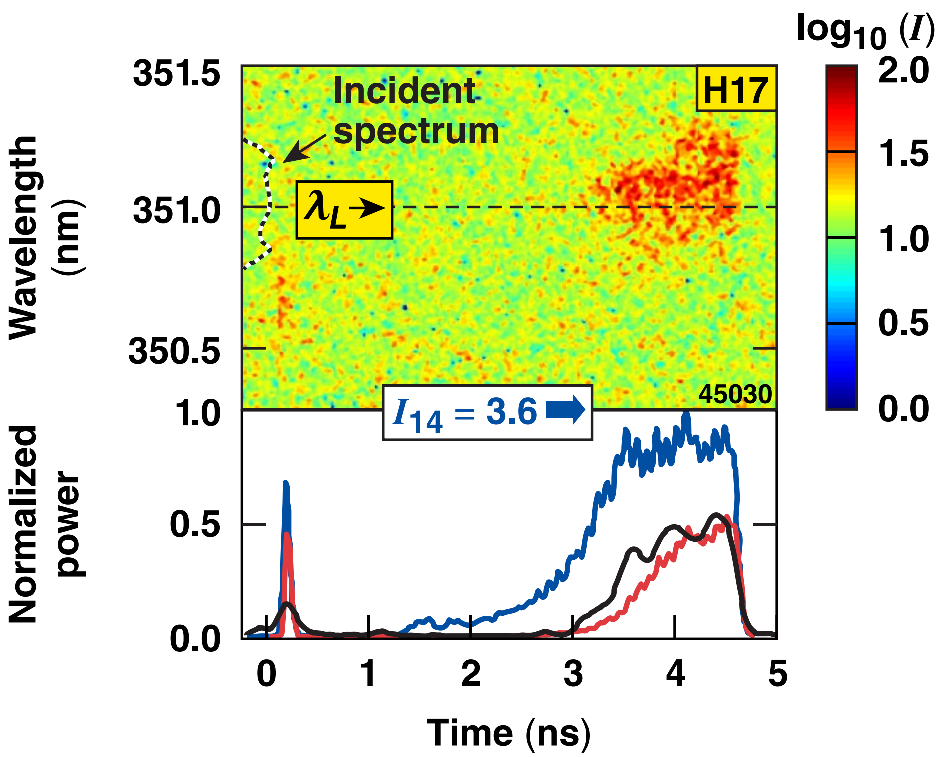

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E16029

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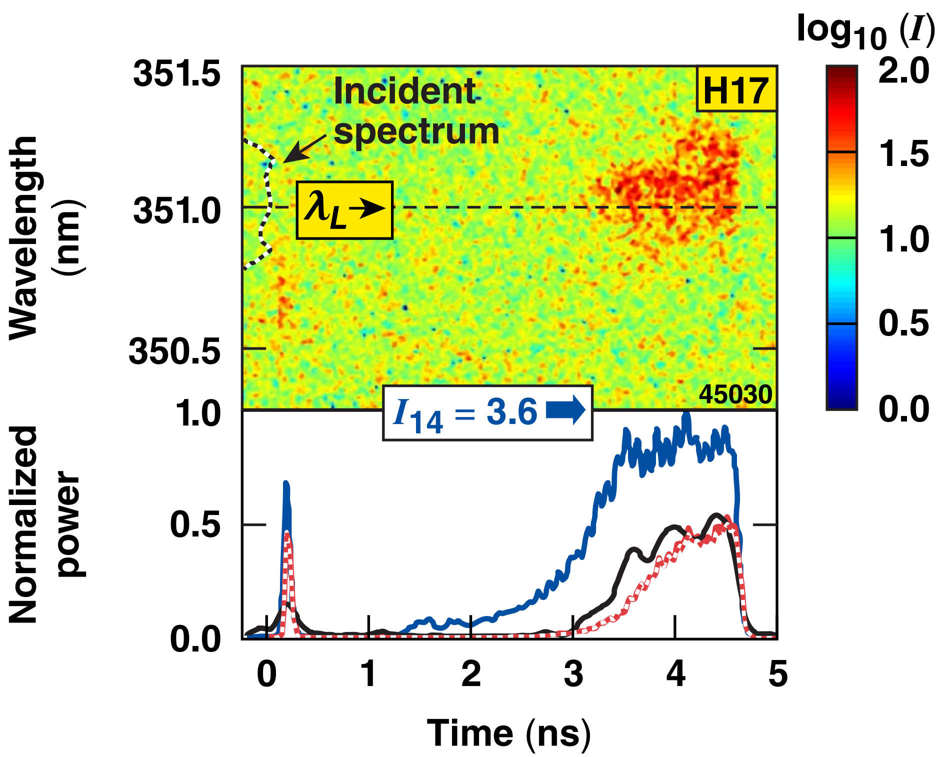

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E16029

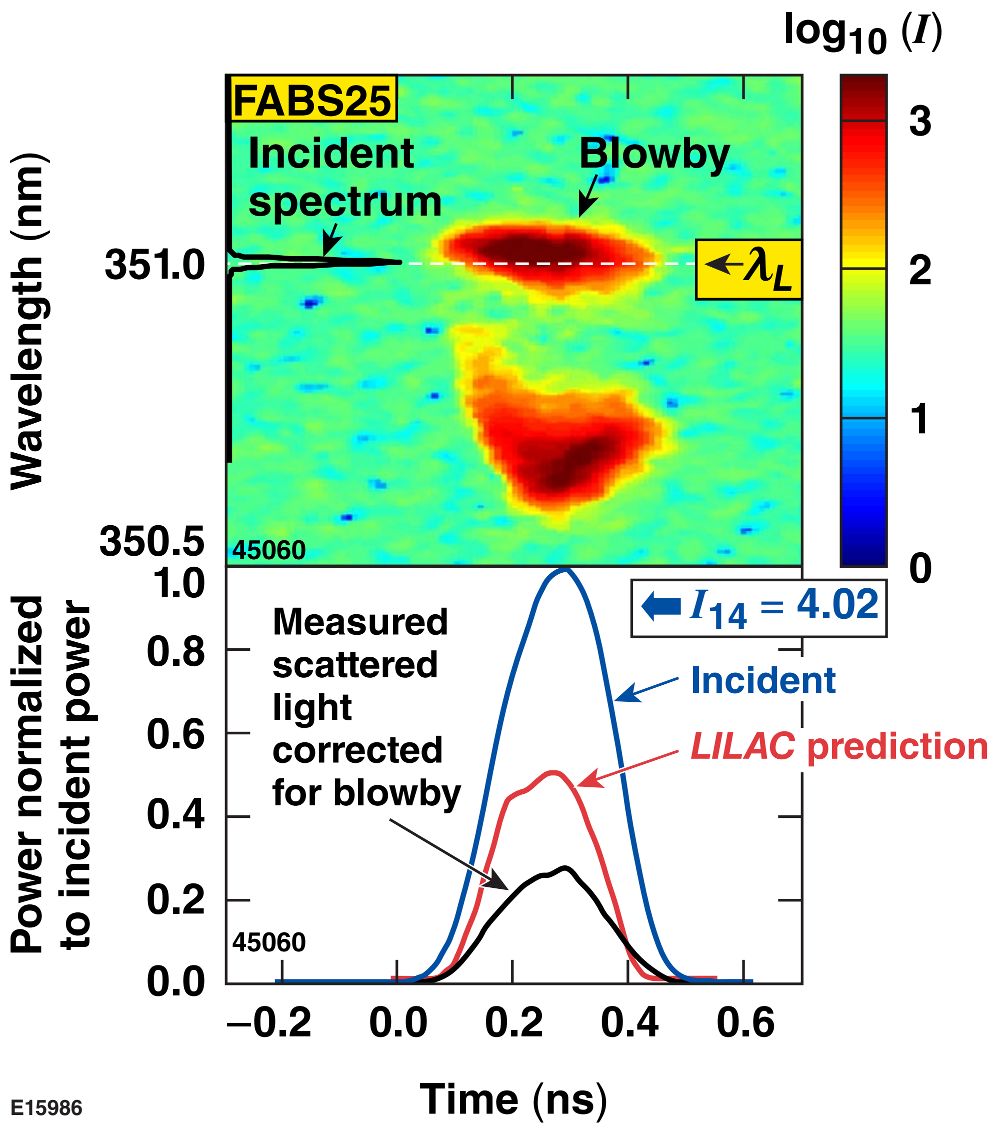
Summary/Conclusions

Direct-drive-implosion experiments show evidence for many different LPI processes that need to be accounted for in target-performance simulations

- The bulk of the absorption at 351-nm irradiation is due to inverse bremsstrahlung absorption.
- During the first 200 ps of irradiation, resonance absorption enhances absorption.
- At later times ($\geq$0.8 ns) enhanced scattering points toward beam-to-beam energy transfer.
- Evidence of the two-plasmon-decay instability is seen in hard-x-ray and $3\omega/2$ self-emission spectra and absorption measurements.

E15976

Resonance absorption is evident during the first 200 ps of irradiation



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E15986

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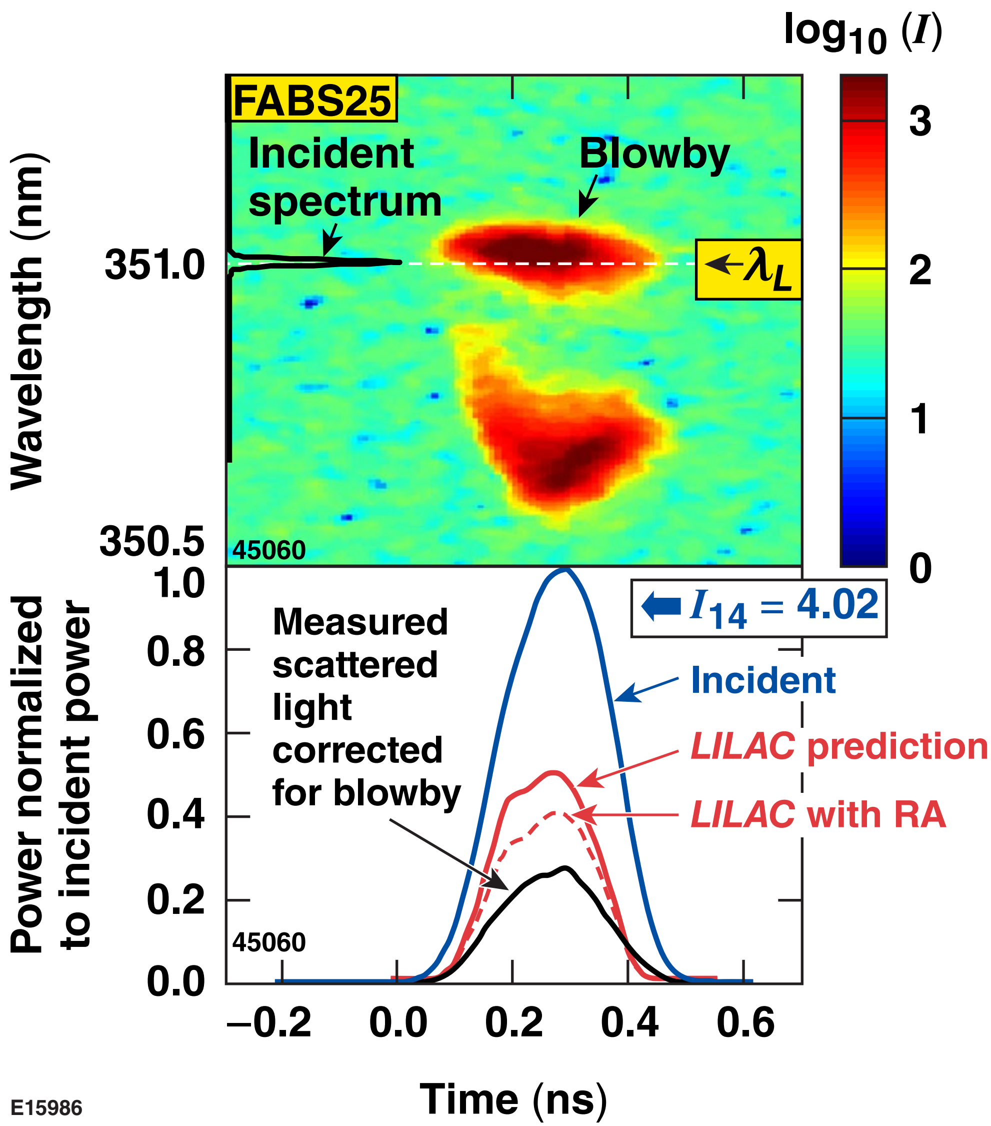

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  - 200-ps laser pulse
  - exp. absorption: 74%
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  - IB and f = 0.06
  - predicted absorption: 52%
- *LILAC* with improved RA model
  - prediction: 63%

E15986

LPI studies in direct-drive-implosion experiments identify many processes

Interaction processes in direct-drive implosions

- **First 200 ps**
  - **enhanced absorption due to resonance absorption**
- **After plasma corona is well established (≥0.8 ns)**
  - **enhanced scattering**
  - **red-peaked scattered-light spectrum**
    - → **This is consistent with beam-to-beam energy transfer via EM-seeded SBS (more definitive experiments still required).**
- **TPD instability**
  - **sensitivity to density gradient and T_e leads to *strongly enhanced $3\omega/2$ and hard x-ray emission after burn-through of thin CD shells***
    - → **Energetic electron preheat continues to be a concern.**
- **Overall spectral features of scattered light have proven to be a sensitive diagnostic for checking hydrodynamic simulations of plasma formation.**