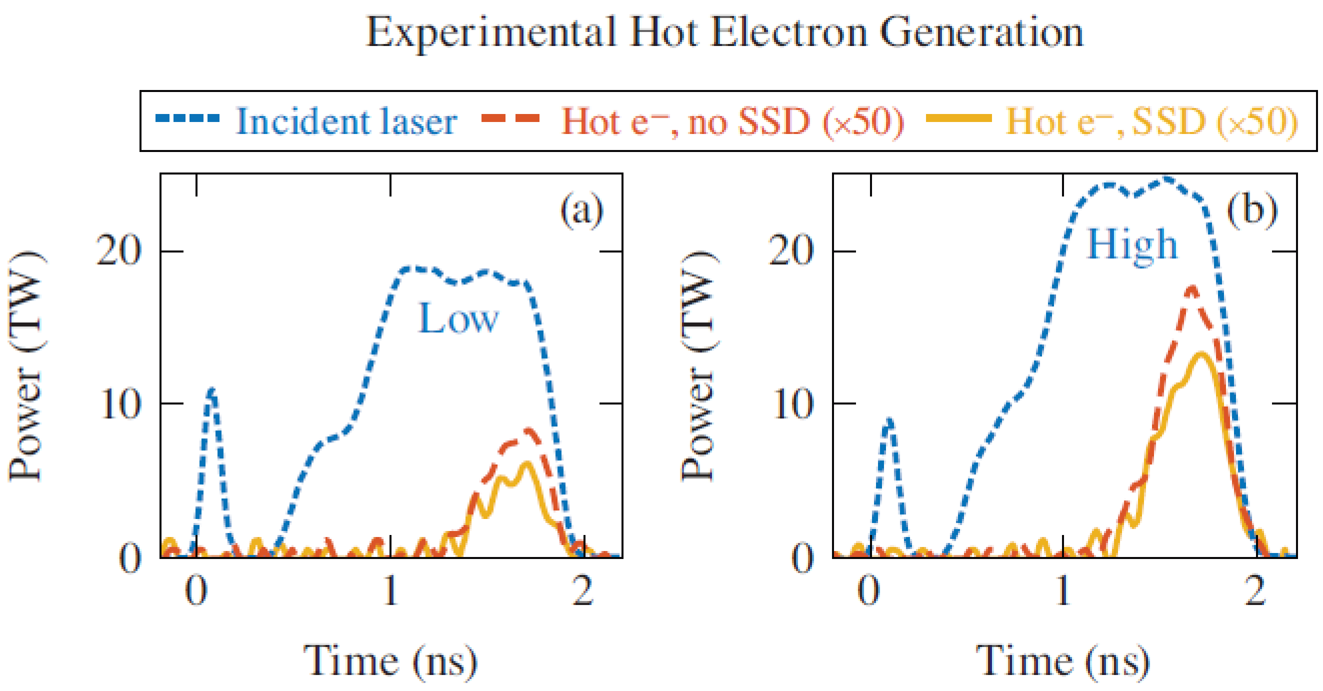
Impact of Spatiotemporal Smoothing on the Two-Plasmon-Decay Instability



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Summary

Smoothing by spectral dispersion (SSD) partially mitigates the two-plasmon-decay instability (TPD) in OMEGA-scale implosions*

- **TPD is a source of anomalous absorption and hot electron preheat in directly driven implosions**
- **Experiments show that ~360-GHz SSD reduces TPD in OMEGA experiments**
- **A hot spot model based on speckle statistics and LPSE scalings for TPD activity reproduces the trends seen in the experimental data**

Speckles and spatiotemporal smoothing need to be accounted for to match experiments quantitatively

* D. Turnbull *et al*., Phys. Plasmas 27, 102710 (2020).

Collaborators

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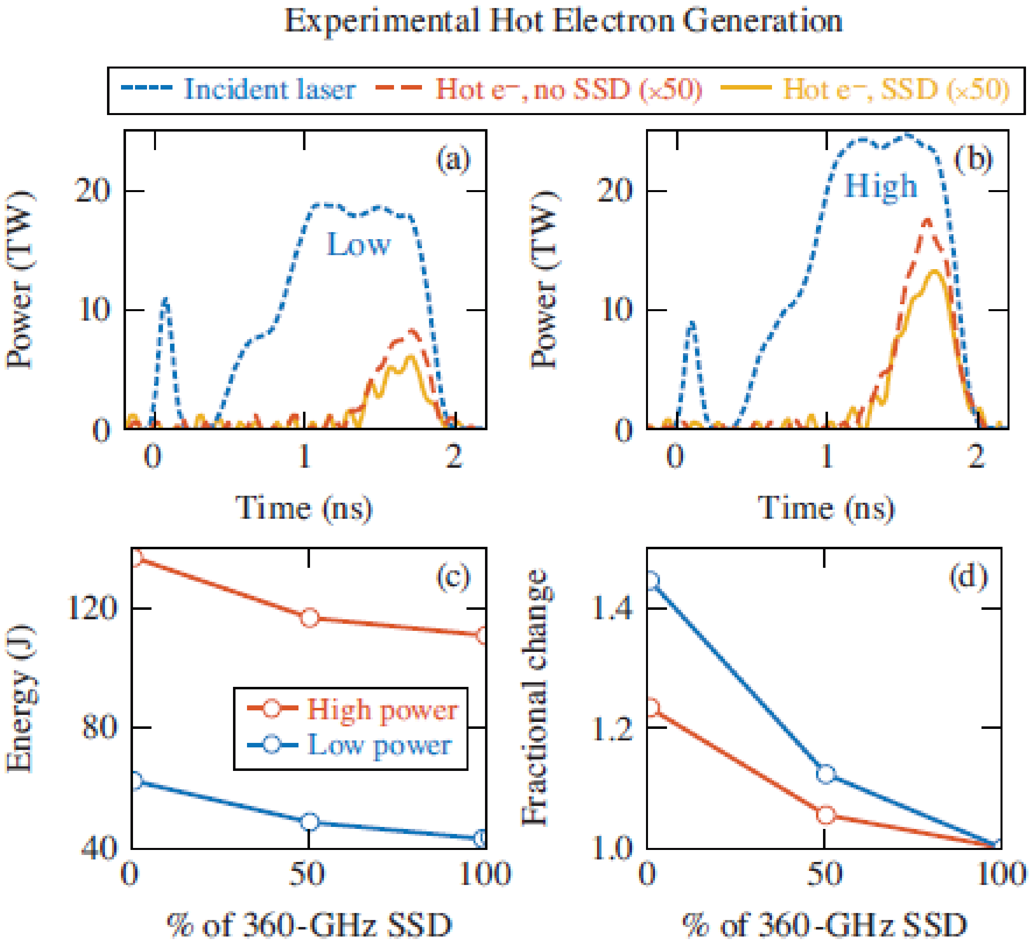
OMEGA implosions* investigated the sensitivity of TPD to SSD at two different peak powers

- Both pulse shapes observed reductions in TPD activity consistent with other recent campaigns
- The absolute increase in hot electrons with SSD off was larger at high power, but the relative increase was more significant at low peak power



*860/960µm-diam., ~27µ-thick, vacuum-filled CH shells, 60-beam illumination with standard pointing, polarization-smoothing, and SG5 (714-µm-diam. FWHM) phase plates

Hypothesis: speckle motion occurs faster than the time to reach steady-state in near-threshold speckles, mitigating the TPD expected in those locations

UR LLE

- **Basic theory of impact of temporal incoherence on LPI predicts reduced linear growth rates and increased thresholds if $\Delta\omega >> \gamma_0$ and $\Delta\omega > v$ (constraints not satisfied for OMEGA-scale TPD)* → bandwidth alone is not expected to affect TPD (verified by LPSE simulations)**

- **But if instability is in a regime where spatial incoherence (speckles) controls growth, the speckle motion caused by spatiotemporal smoothing can be effective in mitigating the instability****
  - **Lowest order effect is to mitigate filamentation†**
  - **Speckle motion can reduce SBS directly if coherence time is less than the time to reach steady-state‡**
  - **SRS thought to grow too quickly for direct mitigation; changes to SRS were attributed to filamentation suppression^**

Little to no existing literature addressed TPD specifically

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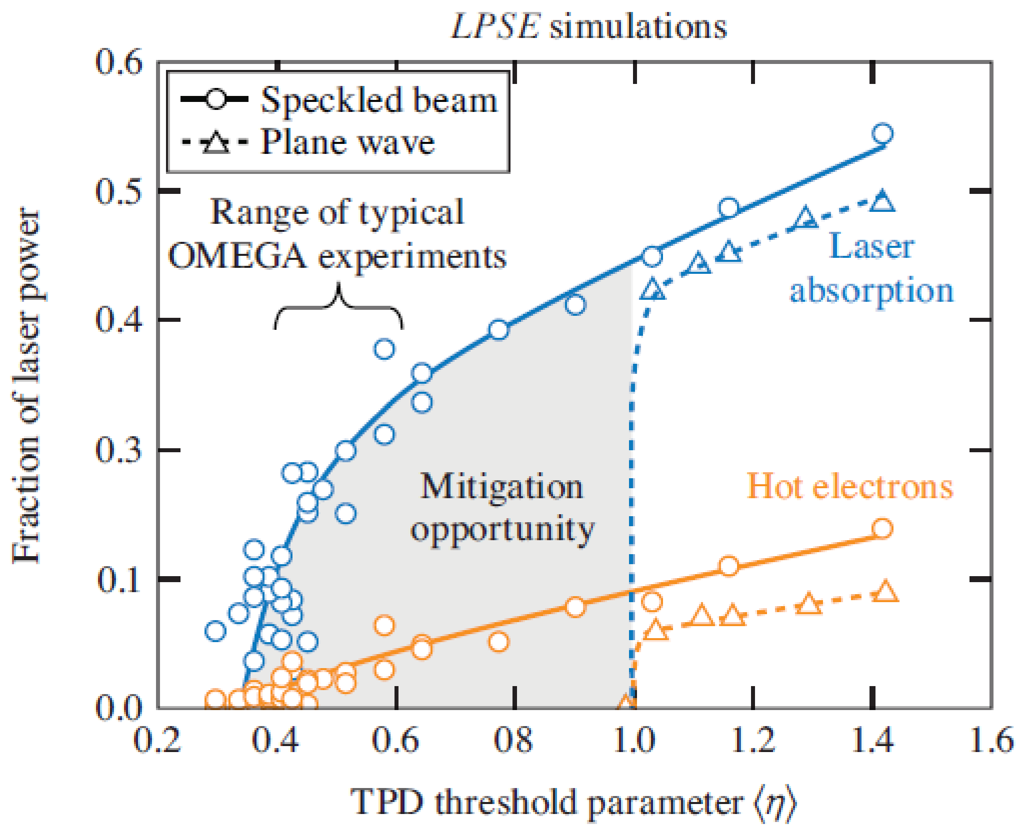
* Valeo and Oberman, PRL (1973); Thomson and Karush, PRL (1974).
** Rose and DuBois, PoF (1993); Rose and DuBois, PRL (1994); Baldis *et al*., PRL (1998).
† Schmitt PoF (1988); Willi *et al*., PoP (1990); Berger *et al*., PoP (1999); Fuchs *et al*., PoP (2000); Tikhonchuk *et al*., PoP (2001).
‡ Berger *et al*., PRL (1995); Mounaix *et al*., PRL (2000); Glenzer *et al*., PoP (2001); L. Divol, PRL (2007).
^ Afshar-Rad *et al*., PoP (1992); Guzdar *et* al., PoF (1993); Montgomery *et al*., PoP (1996); Moody *et al*., PRL (2001).

OMEGA implosions take place in the parameter space where the instability only exists due to speckles—exactly where smoothing can be effective

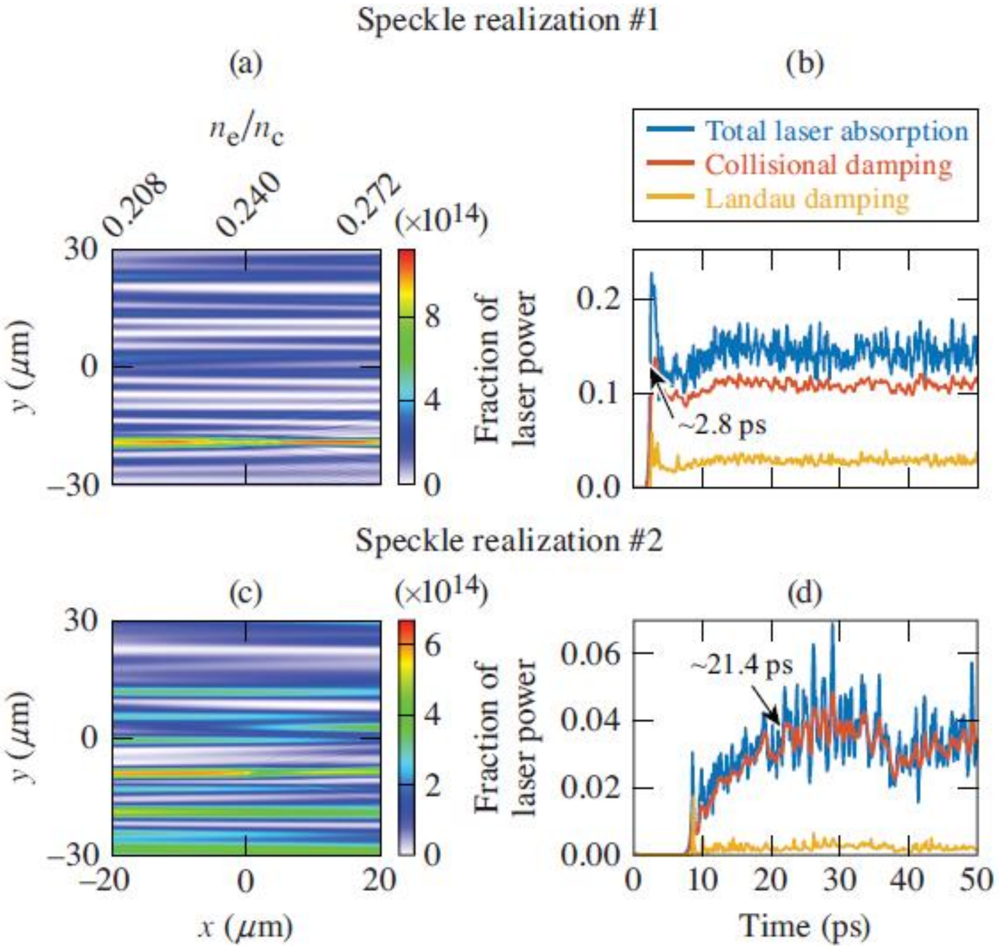
- ***LPSE*** **simulations used a single, normal-incidence beam and plasma conditions guided by LILAC simulations of the experiments (T_e=2.5 keV, L=150μm, Z=3.5)**
- **A plane-wave beam recovers the Simon threshold η=1 [where $\eta = I_{14}L/(233T_e)$], but speckles reduce the threshold by ~3x**
- **OMEGA experiments are situated in between the speckled-beam and plane-wave thresholds**



In this regime, spatiotemporal smoothing *on TPD-relevant timescales* can in principle mitigate the instability

The LPSE simulations were interrogated to determine TPD-relevant time scales

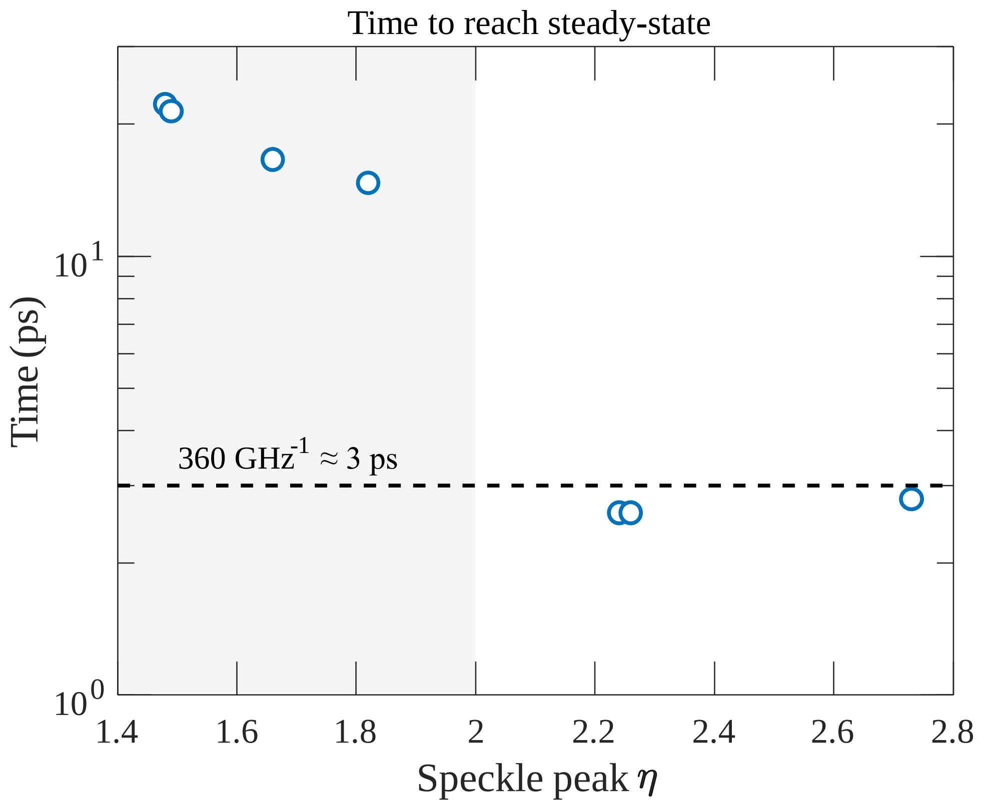
- **Two simulations with similar average intensities but different speckle statistics show key differences between high- and low-intensity speckles**
  - **Intense speckles reach steady-state* faster (few ps)**
  - **Moderate speckles take much longer (~20ps)**
  - **Intense speckles generate relatively more hot electrons for a given amount of laser absorption**



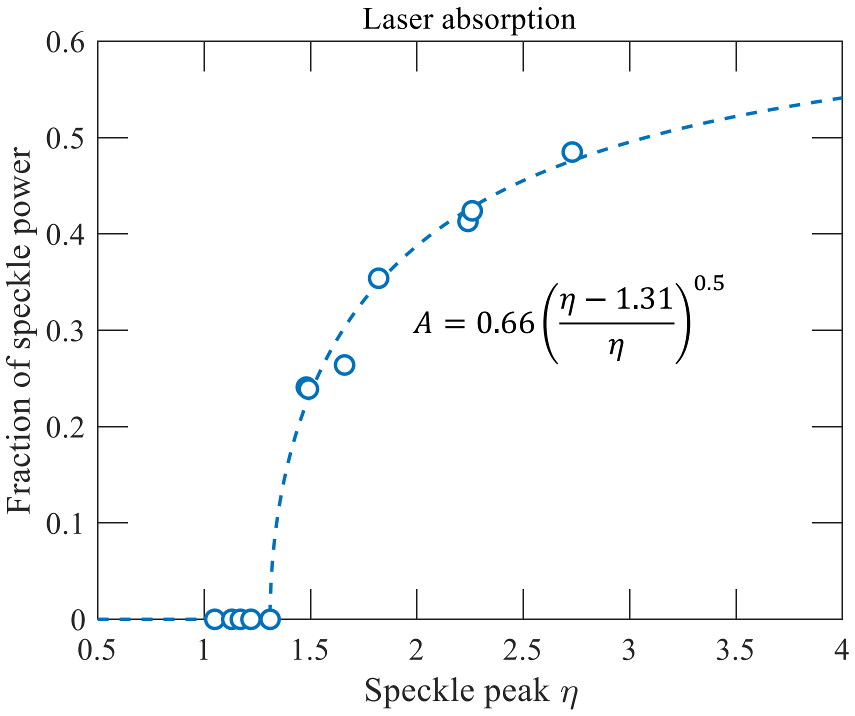
***steady-state defined as when the 2ps-running average reaches the late-time (20-50ps) average**

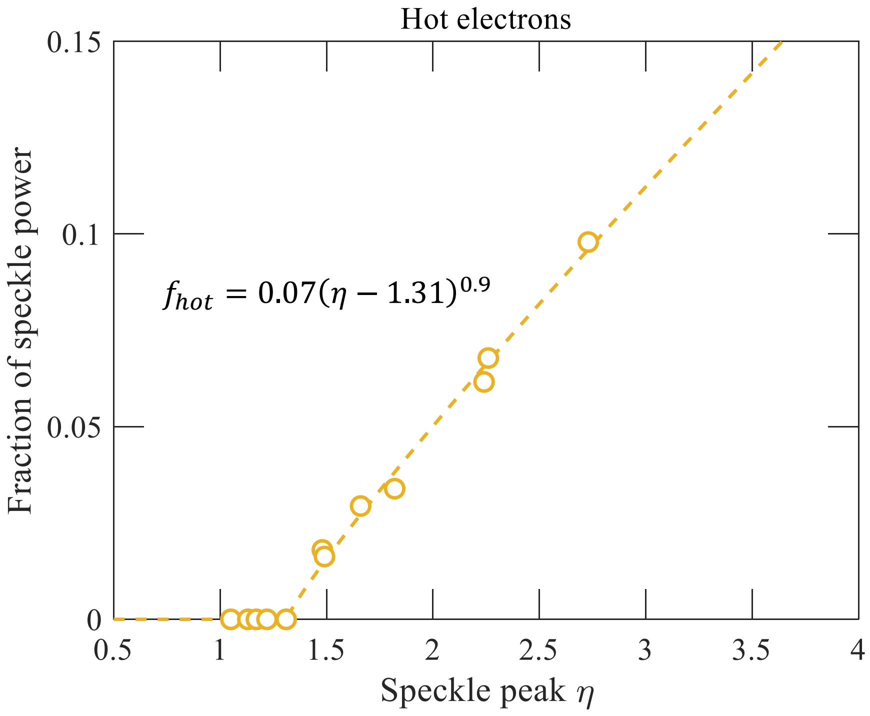
All LPSE simulations with a single unstable speckle were used to determine time to reach steady-state as a function of speckle peak intensity

- **Steady-state is reached on long timescales**
  - ***Absolute instability plays a key role***
  - ***Dominant saturation mechanism is mode coupling to ion acoustic waves***
- **Speckles with peak intensity η≤2 are very likely those stabilized with SSD**



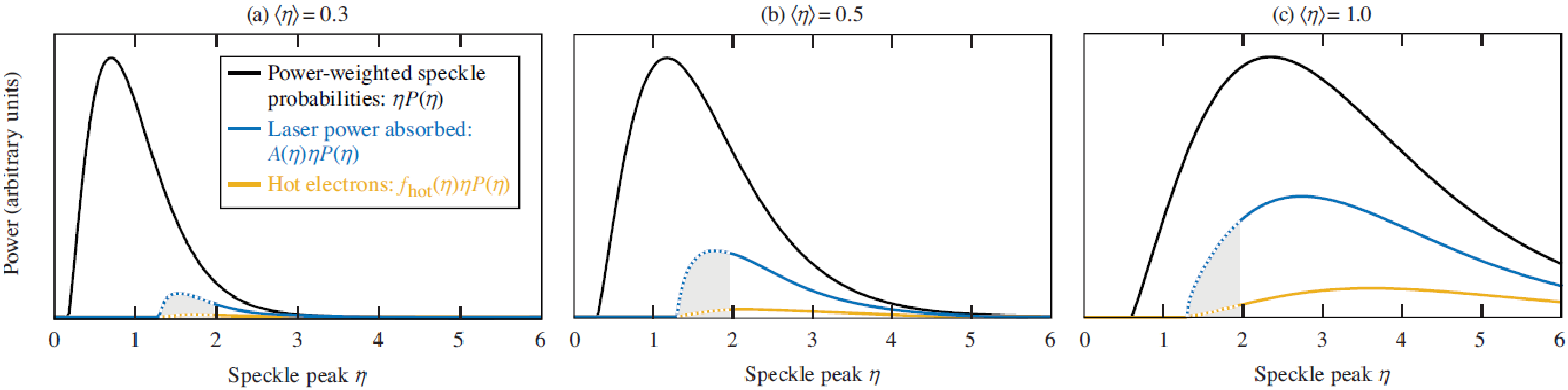
Laser absorption and hot electron intensity scalings were also determined from the LPSE simulations for use in a hot spot model





Combining speckle statistics with the LPSE scalings yields a hot spot model to predict TPD activity, with or without SSD, for any average intensity

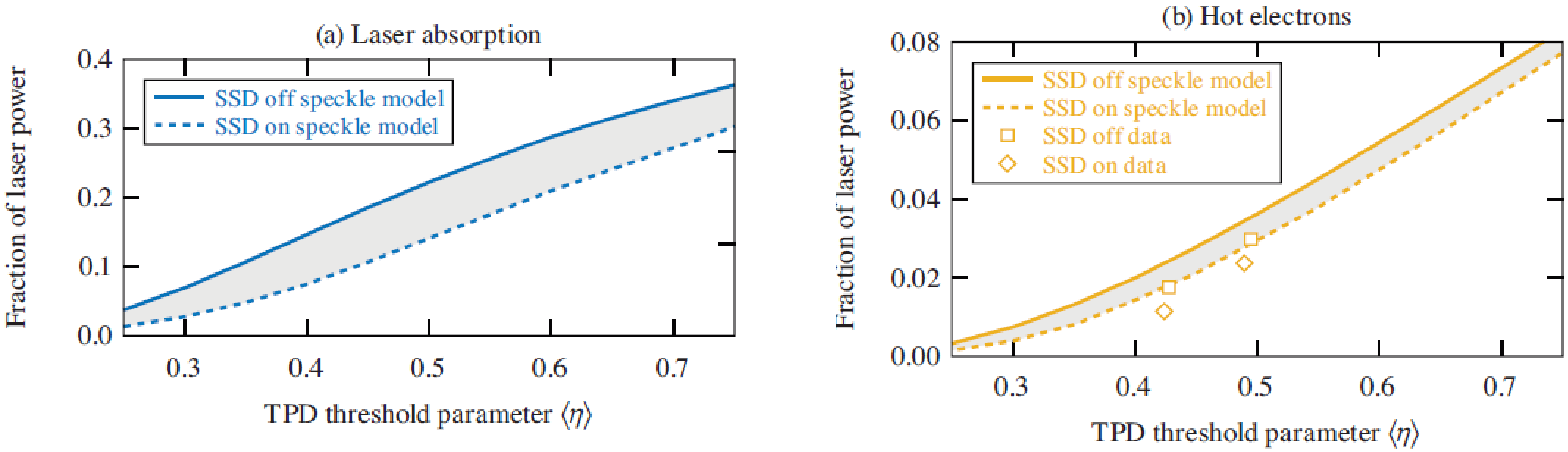
- **Speckle probably distribution $p(\eta) = -dM/d\eta$, where abundance $M \sim \left(\left(\frac{1}{2}+\frac{\pi}{4}\right)\frac{\eta}{\langle\eta\rangle}+\frac{1}{2}\right) exp\left(-\frac{\eta}{\langle\eta\rangle}\right)$ ***



We see qualitatively that SSD is likely to be more effective at low-average-intensity (close to threshold), with diminishing benefits at high intensity

* Garnier, PoP (1999); Maximov *et al.*, PoP (2001).

The model's hot electron predictions are in reasonable agreement with the data, and the differences between low/high power and SSD on/off are well reproduced



The general success of the hot spot model in reproducing data seems to confirm that it is capturing the relevant physics

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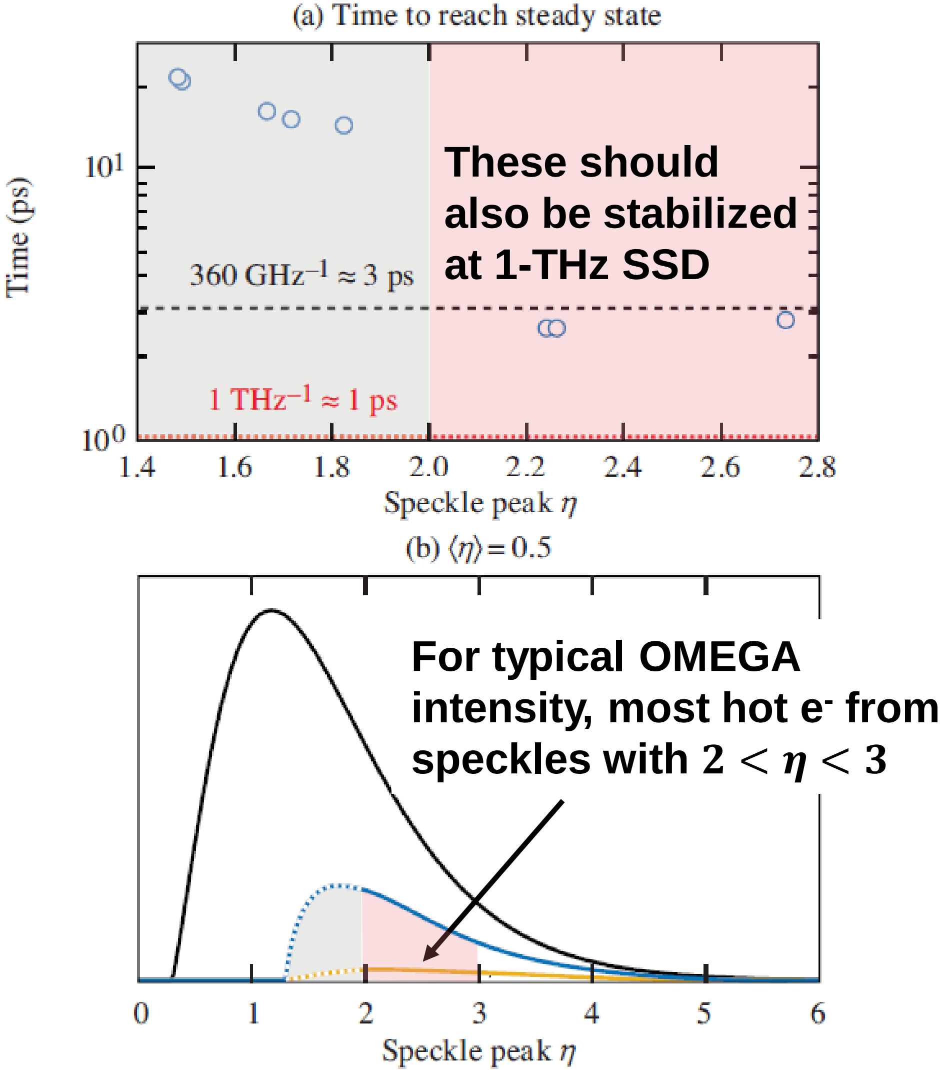
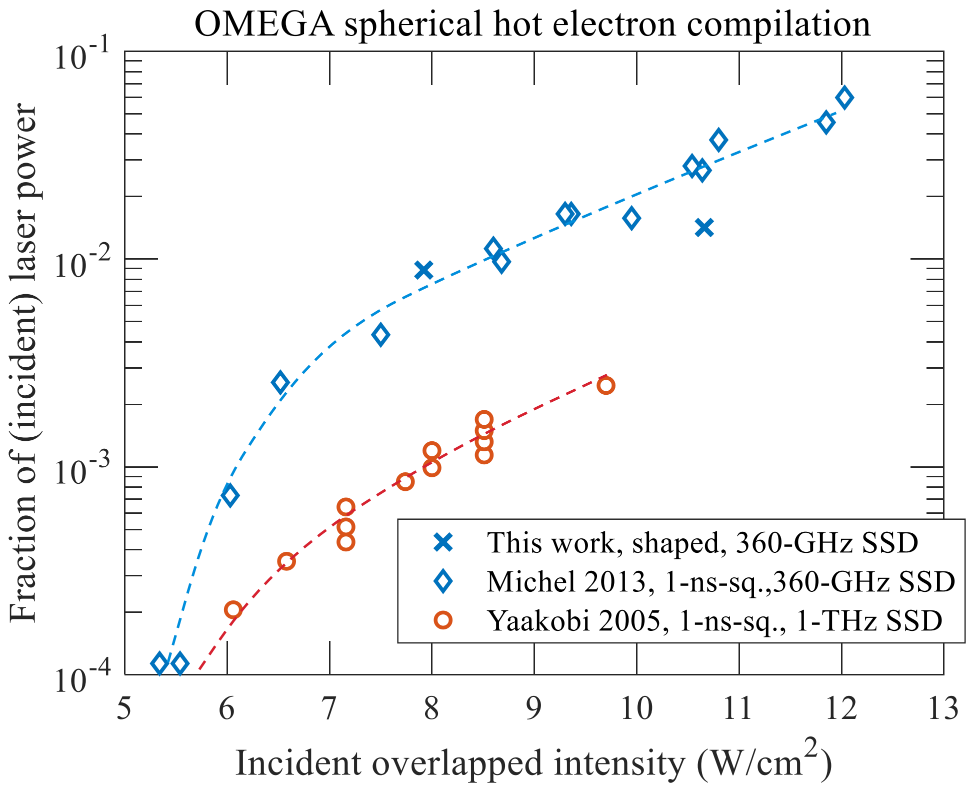
By the logic of the hot spot model, more SSD bandwidth should provide greater TPD mitigation





Legacy 1-THz OMEGA spherical data does support this prediction, so larger bandwidth could be restored if hot electron mitigation is required