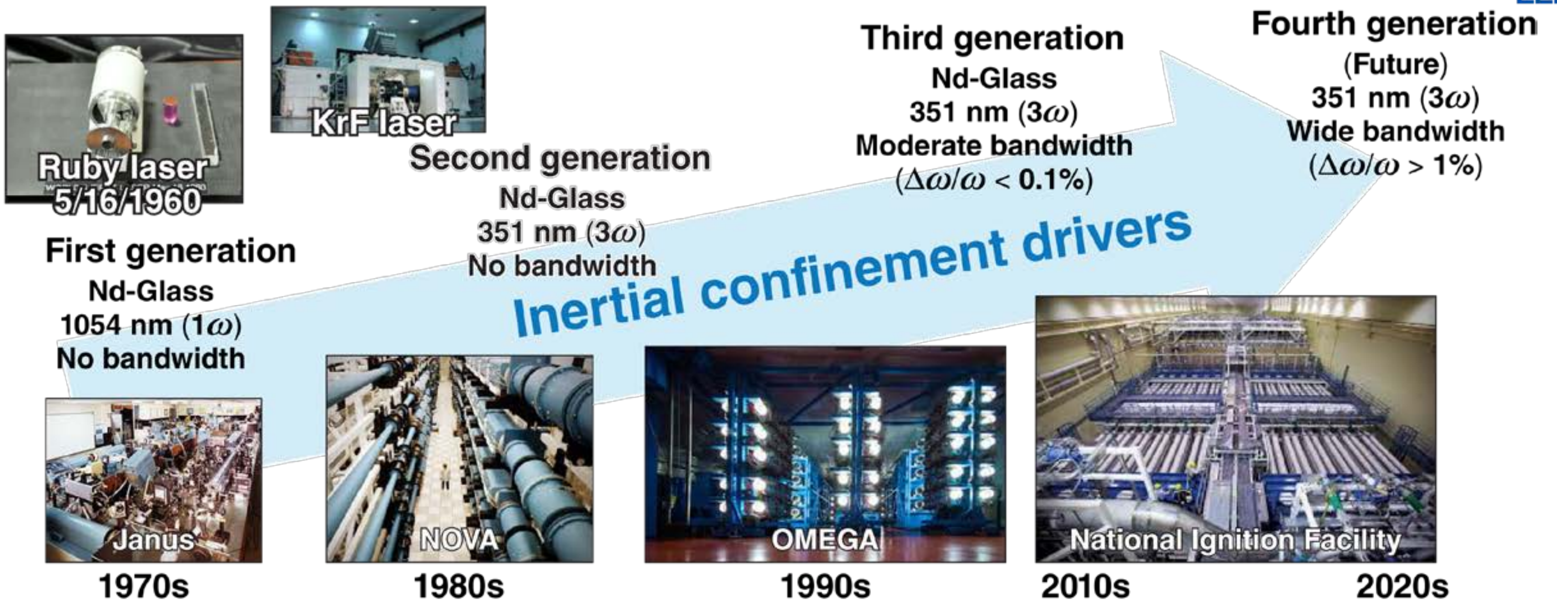
Innovative Science and Broadband Lasers—A Path to an Expanded ICF Design Space



Dustin H. Froula
Associate Professor, Physics Department
Plasma & Ultrafast Physics Group Leader
Laboratory for Laser Energetics

Fusion Power Associates
Washington, D.C.
4 December 2018

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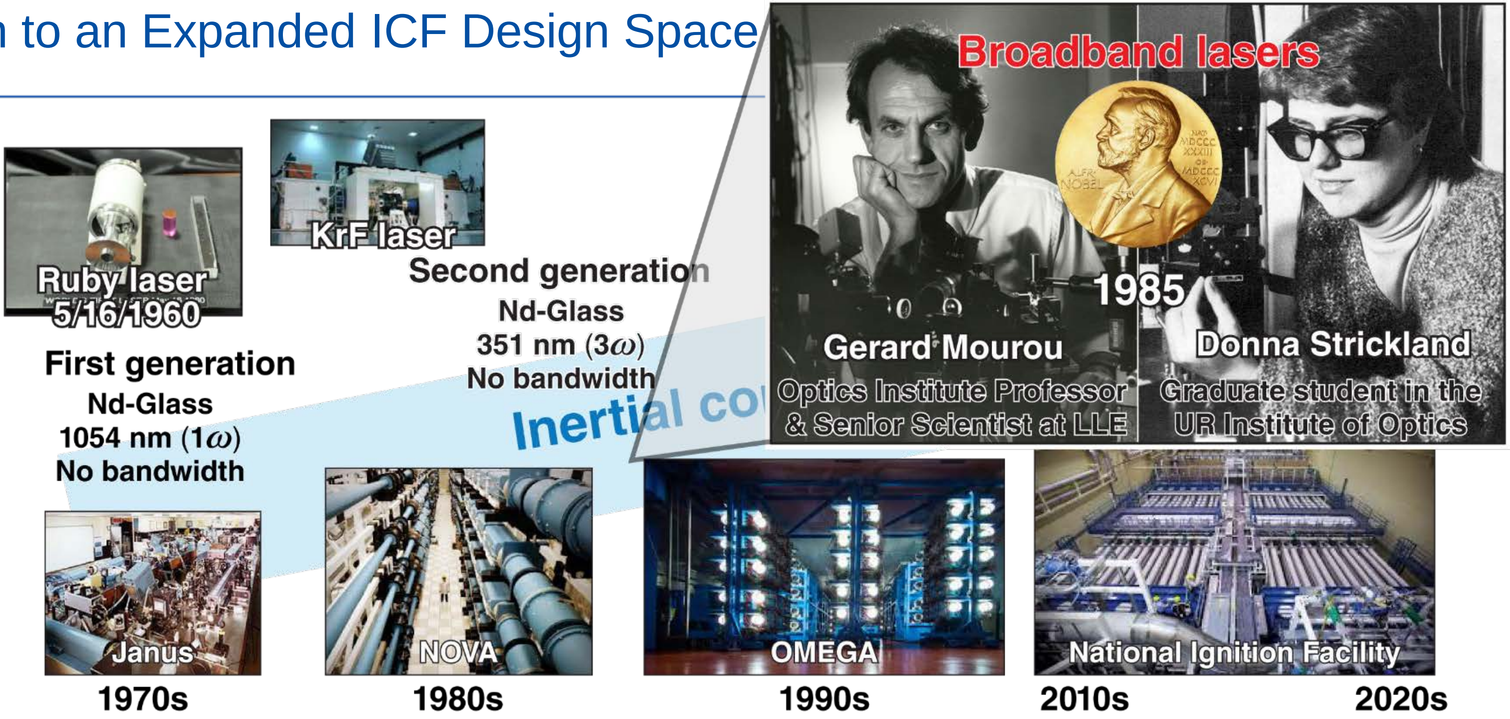

UR LLE

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The Laboratory for Laser Energetics (LLE) at the University of Rochester is working to build a laser system that can expand the design space for all three (LID, LDD, MagLIF) approaches to ICF

- A more-complete understanding of laser–plasma instabilities will lead to fusion designs that include ignition
- A broad physics portfolio brings solutions to future ICF problems, while attracting and maintaining a vibrant community required for innovation
  - fusion, laser wakefield acceleration, laser-plasma amplifiers, and ultrashort pulse science all attract the top scientists to plasma physics
- Today’s innovative concepts become tomorrow’s ICF solutions
  - LLE is using its experience in broadband lasers to build a test bed for demonstrating LPI mitigation using ultra-large bandwidth ($\Delta\omega/\omega$>1%)

LID: Laser Indirect Drive
LDD: Laser Direct Drive
MagLIF: Magnetized Liner Inertial Fusion

Collaborators

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J. Katz, R. Boni, J. D. Zuegel, V. N. Goncharov, E. M. Campbell

Laboratory for Laser Energetics
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Lawrence Livermore National Laboratory

M. Glensky, K. Peterson
Sandia National Laboratories

J. W. Bates, A. Schmitt, and J. L. Weaver

Naval Research Laboratory

J. F. Myatt
University of Alberta

National Nuclear Security Administration

U.S. DEPARTMENT OF ENERGY | Office of Science

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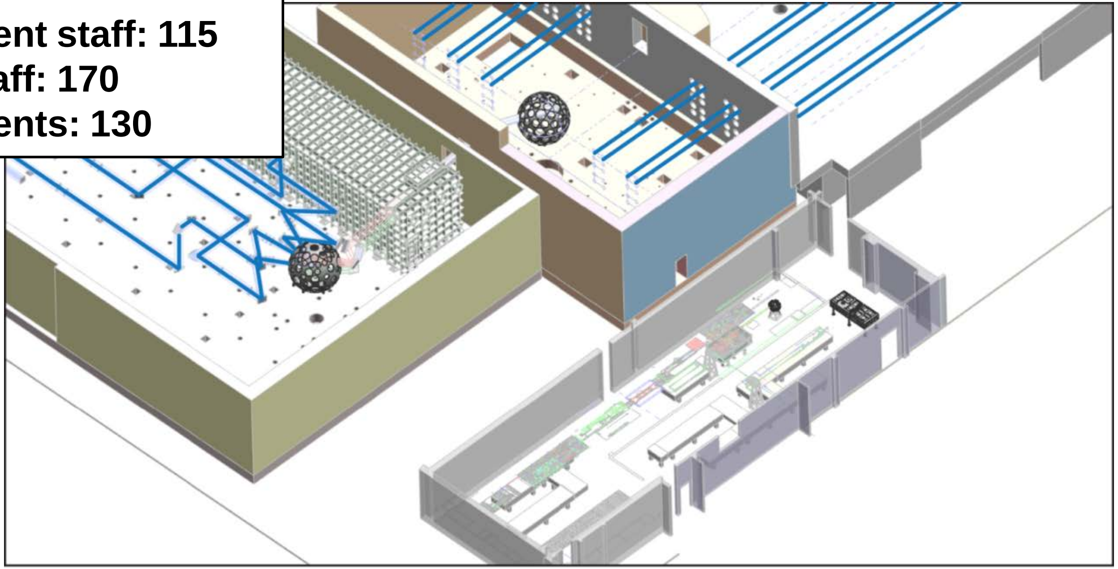
The combination of plasma physicists, laser scientists, and optical engineers at the University of Rochester's LLE provide a unique environment for innovative research

Laboratory for Laser Energetics
University of Rochester

- **Faculty equivalent staff: 115**
- **Professional staff: 170**
- **University students: 130**



E27037

The LLE operates the world's largest lasers in an academic setting

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University of Rochester

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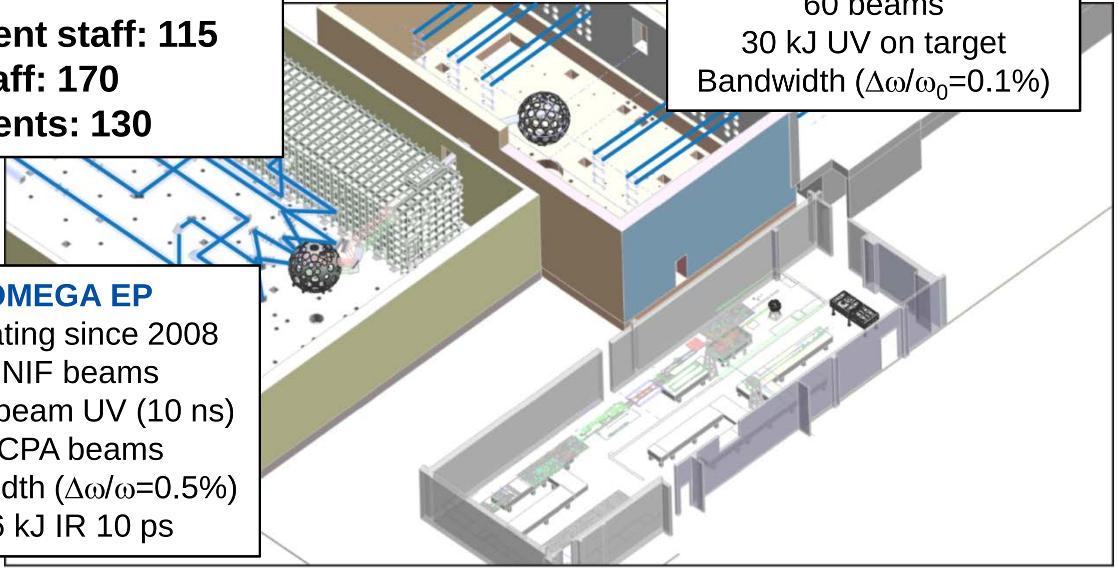
OMEGA
Operating since 1995
60 beams
30 kJ UV on target
Bandwidth ($\Delta\omega/\omega_0$=0.1%)



E27037

OMEGA EP
Operating since 2008
4 NIF beams
6.5 kJ/beam UV (10 ns)
2 CPA beams
Bandwidth ($\Delta\omega/\omega$=0.5%)
2.6 kJ IR 10 ps

More than half of OMEGA and OMEGA EP's (~2000 shots/year) are for external users

The LLE has an active laser science group that has been developing broadband laser technologies since the advent of chirped-pulse amplification

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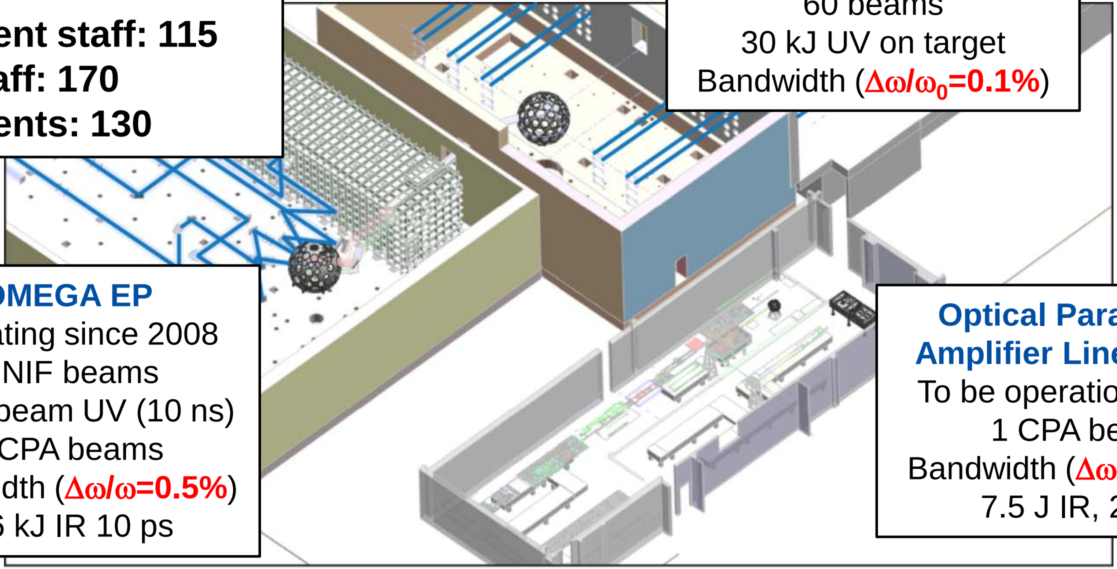

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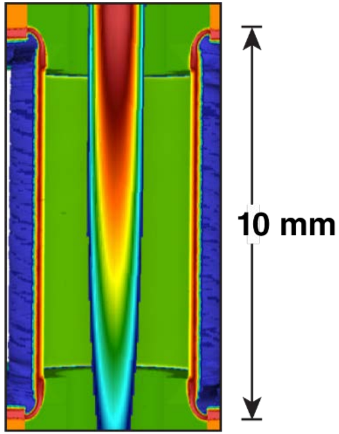
Optical Parametric Amplifier Line (OPAL)
To be operational 2019
1 CPA beam
Bandwidth (**$\Delta\omega/\omega_0$=20%**)
7.5 J IR, 20 fs

The short-pulse laser technologies developed over the last two decades are leading directly to broadband lasers that will mitigate laser-plasma instabilities in ICF

Laser-plasma instabilities set the maximum laser intensities for each inertial confinement fusion (ICF) design

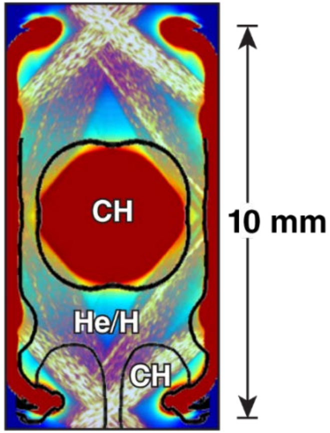
MagLIF

LPI Limitations
Filamentation
Stimulated Brillouin scattering
Stimulated Raman scattering



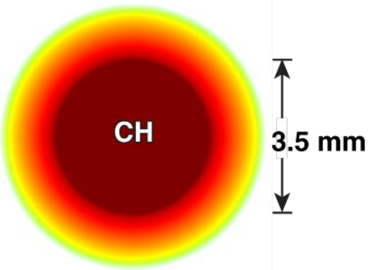
Indirect Drive

LPI Limitations
Cross-beam energy transfer
Stimulated Brillouin scattering
Stimulated Raman scattering



Direct Drive

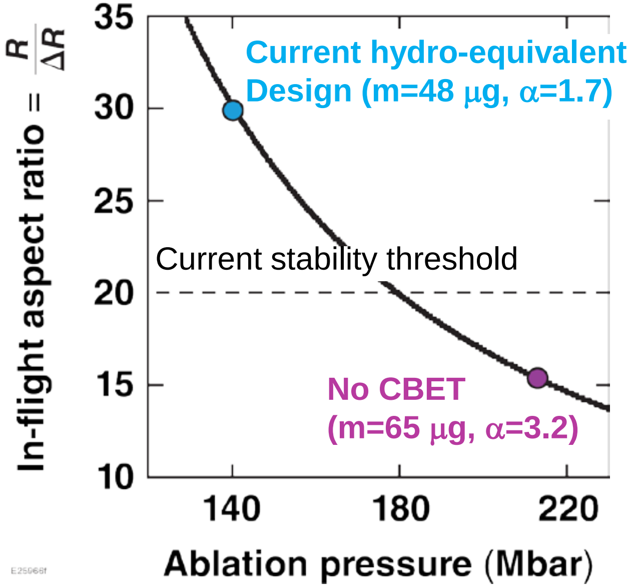
LPI Limitations
Cross-beam energy transfer
Two-plasmon decay
Stimulated Raman scattering

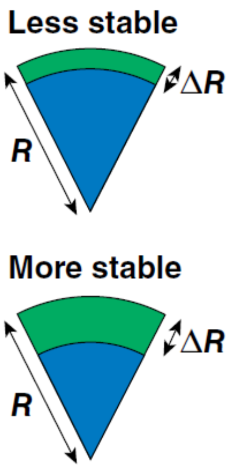


Mitigation of LPI would significantly expand the ICF design space to include ignition

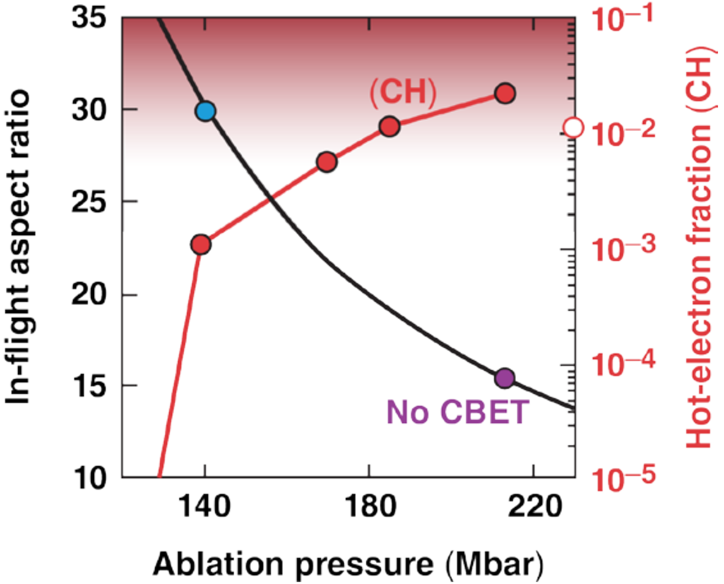
Mitigation of cross-beam energy transfer (CBET) would increase the ablation pressure for direct-drive implosions by ~50% allowing more stable implosions

Constant hydrodynamically equivalent hot spot pressure





Increased hot electrons will prevent compression



For hydrodynamically equivalent implosions on OMEGA, an increase in the hydrodynamic stability threshold or mitigation of both CBET and hot electron generation is required

LPI modeling predicts that bandwidth can mitigate both CBET and hot electron generation in hydrodynamic-equivalent ignition implosions on OMEGA

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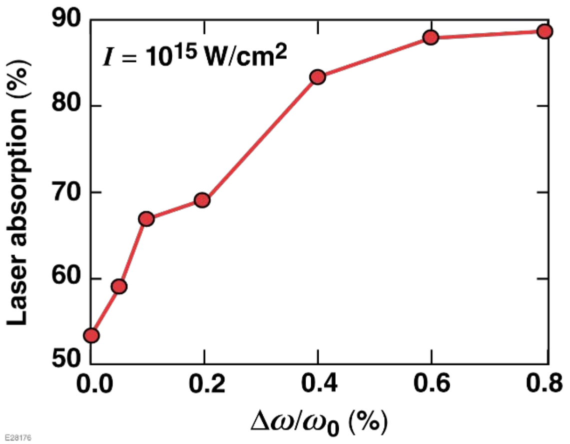
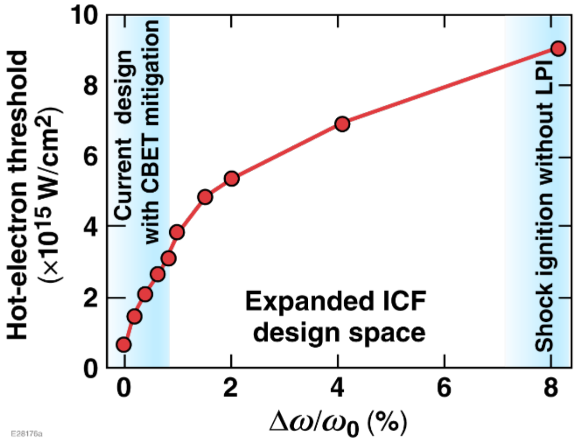
Cross-Beam Energy Transfer (Increased Drive Pressure)



R. Follett *et al.*, submitted Phys. Plasmas (2018)
J. Bates *et al.*, PRE **97**, 61202 (2018)

Increasing Δω/ω>0.5% will allow stable implosions on OMEGA (IFAR=15)

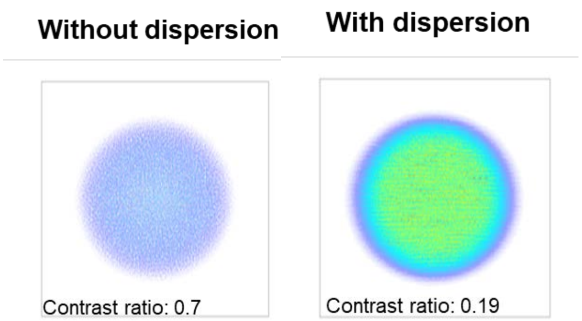
Two-Plasmon Decay (Hot-Electron Mitigation)



R. Follett *et al.*, submitted Phys. Plasmas (2018)

Increasing Δω/ω>1% will mitigate both CBET and hot electrons and allow for hydro-equivalent ignition

Improved Imprint (<1-ps asymptotic smoothing)



Improved imprint will further expand the direct-drive design space

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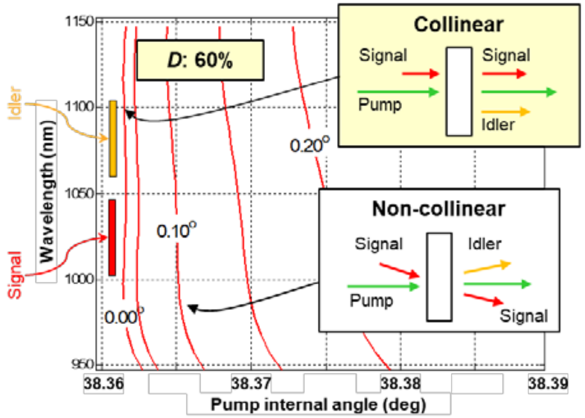
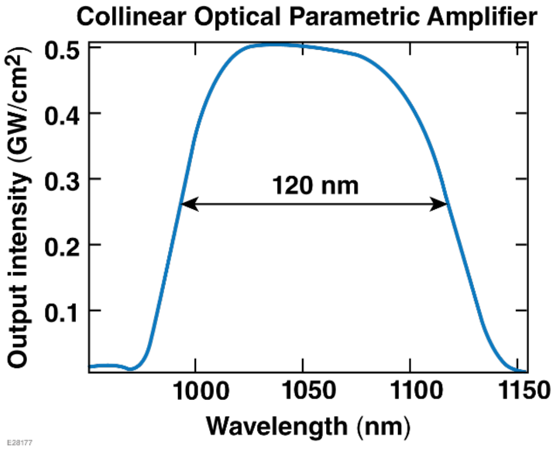
To meet these bandwidth requirements (Δω/ω>1%), LLE is building a Fourth-generation Laser for Ultra-broadband eXperiments (FLUX) to study LPI mitigation

Broadband DKDP Optical Parametric Amplifiers



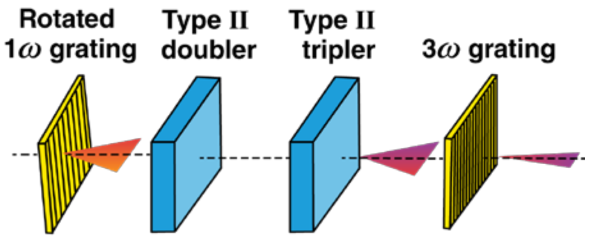
Amplifiers developed for ultra-short-pulse lasers will be adapted for ICF driver

High-Power Amplification



Modeling shows that collinear OPA's can amplify Δω/ω=12%

Broadband Frequency Conversion (Δω/ω=3% UV)

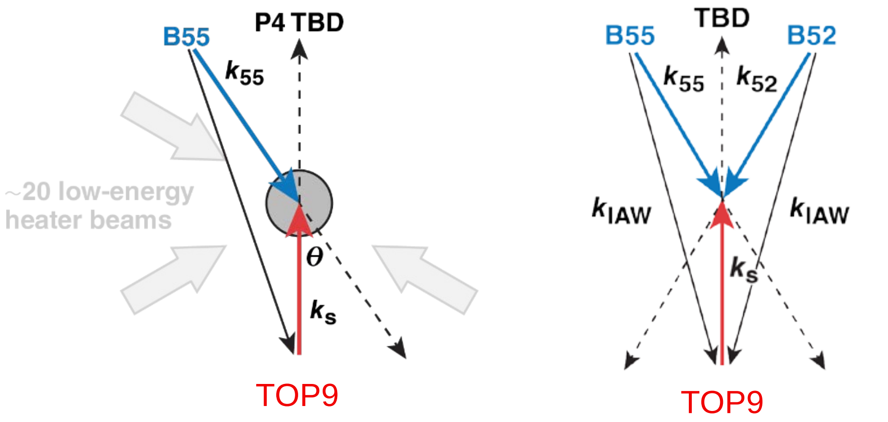


"Efficient Harmonic Generation with a Broadband Laser," M. D. Skeldon *et al.*, IEEE J. Quantum Electron **28**(5), 1389 (1992)

Gratings will be used to phase match for efficient third harmonic frequency generation

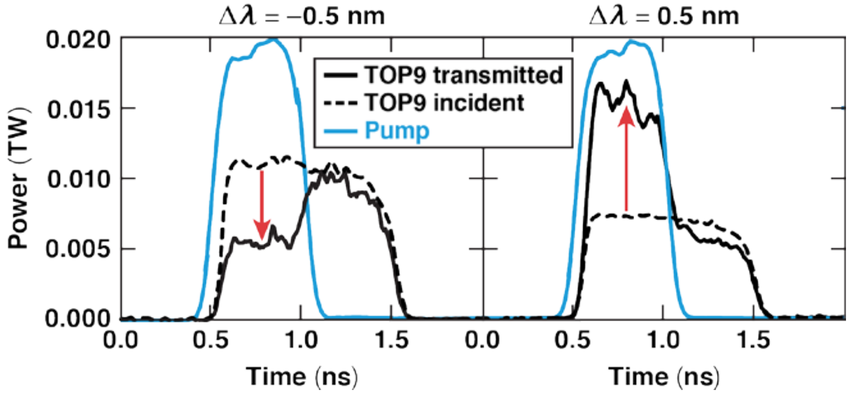
An LPI platform is being developed on OMEGA to better understand CBET and to test the physics of broadband mitigation

The laser team developed a novel tunable system using the OMEGA EP broadband amplifiers to achieve $\Delta\lambda_{UV}$ =3 nm



The TOP9* was operational ~12 months after the concept was presented at the National LPI Workshop

The initial CBET experiments are testing the limitations of the CBET models that are implemented in our codes (*LPSE, LILAC, DRACO, HYDRA*)



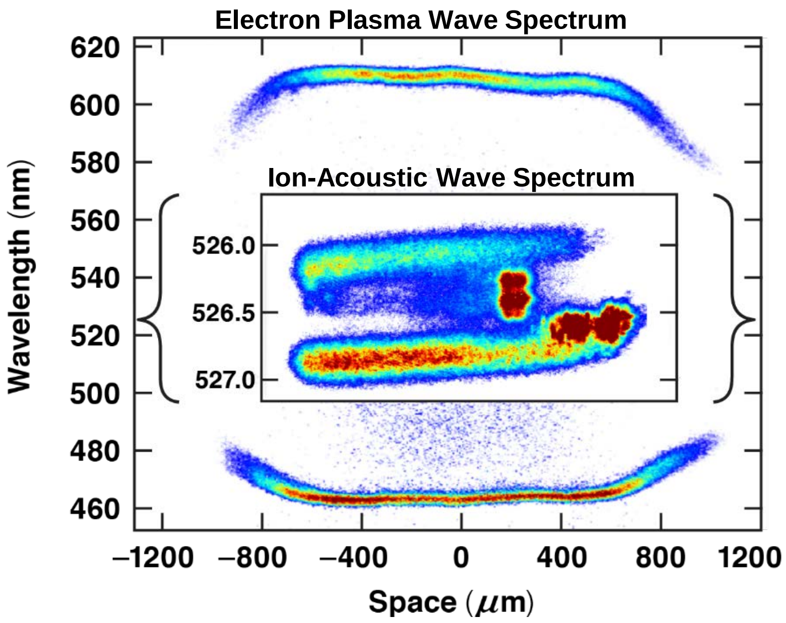
The TOP9* activation shots show energy transferred to and from the pump

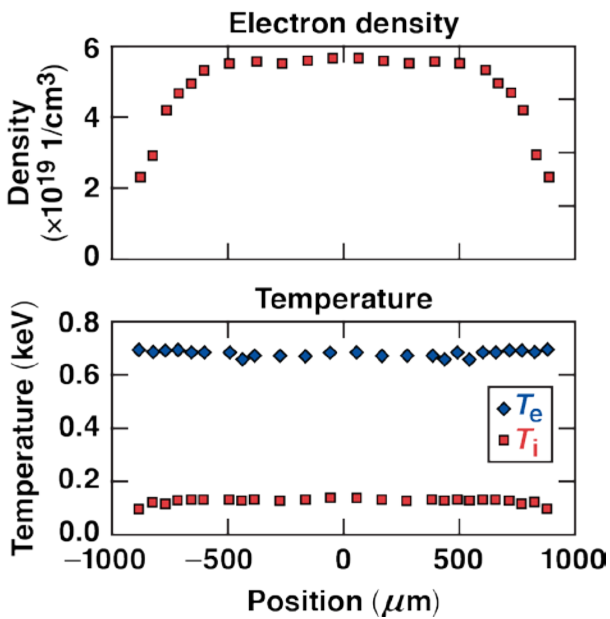
* TOP9: Tunable OMEGA Port 9

Aaron Hansen

Physics Grad. Student

The plasmas are being characterized using collective Thomson scattering to isolate the CBET physics from uncertainties in the plasma conditions



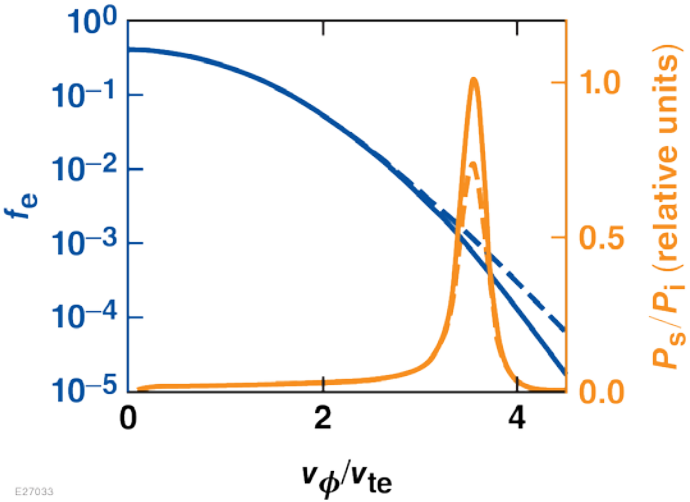


Robert Henchen

Physics PhD 2018

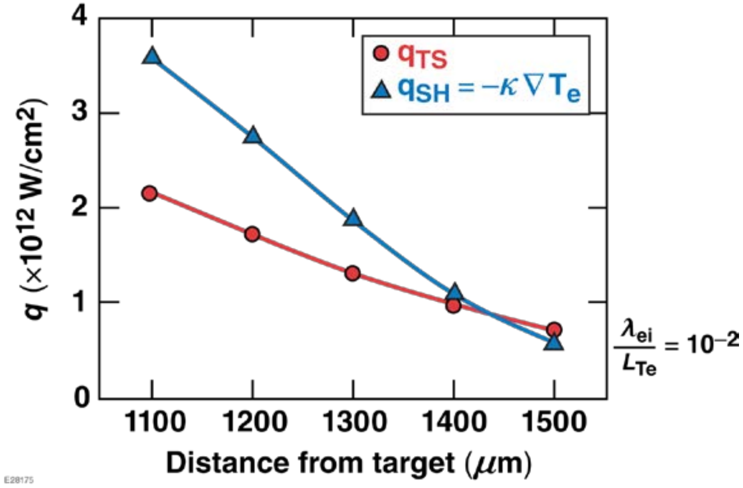
We are expanding Thomson scattering away from just measuring the macroscopic local state variables (e.g., T_e, n_e) to include measurements of heat flux

The collective spectrum is sensitive to the shape of the electron distribution function



The amplitude of the electron plasma wave features become a measure of the heat flux

These results show direct measurement of nonlocal thermal transport*



Measurements show classical theory over predicts the heat flux close to the target but agrees far away

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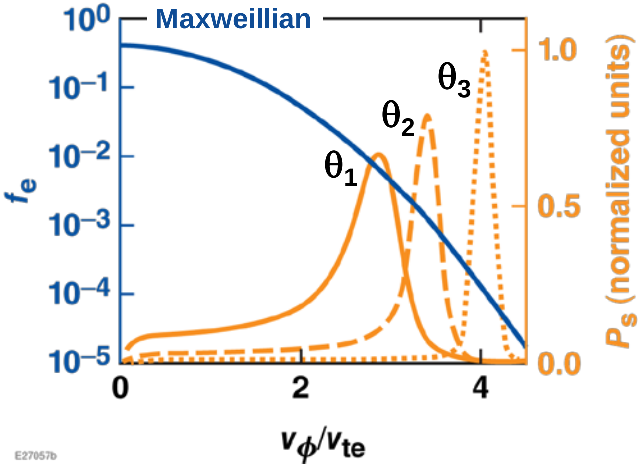
* R. Henchen *et al.*, Phys. Rev. Lett. **121**, 125001 (2018)

Avi Milder

Physics Grad. Student

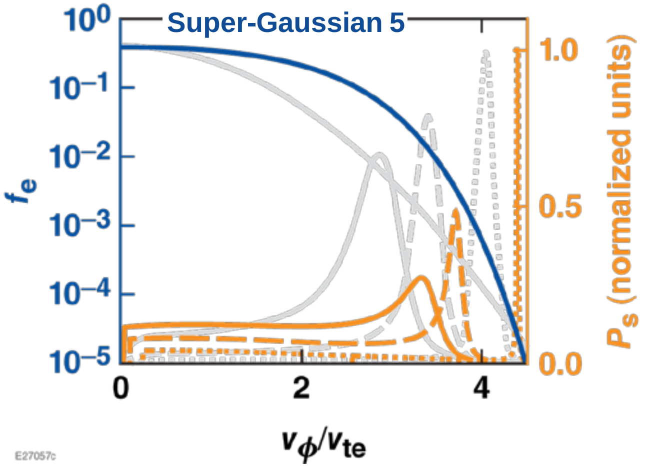
Building on the heat flux results, we are extending the concept to measure the complete electron distribution function

New 120º k-resolved Thomson scattering



Each scattering angle probes a different part of the distribution function

Super-Gaussian electron distribution function



Multiple scattering angles will allow complete arbitrary distribution functions to be measured

These measurements will provide insight into the role of the electron distribution function on laser-plasma instabilities and thermal transport.

By combining advanced modeling, state-of-the-art laser science, and well-diagnosed plasma physics experiments an optimum ICF laser driver will be defined by 2023

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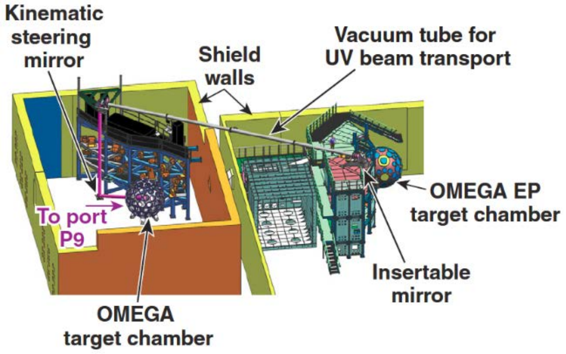
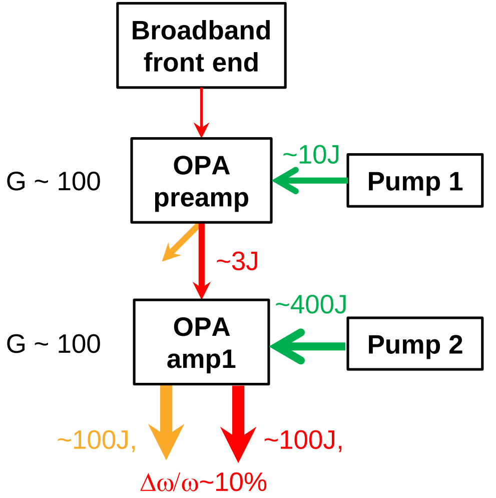
The TOP9 laser feeds the OMEGA LPI Platform (2017-2019)



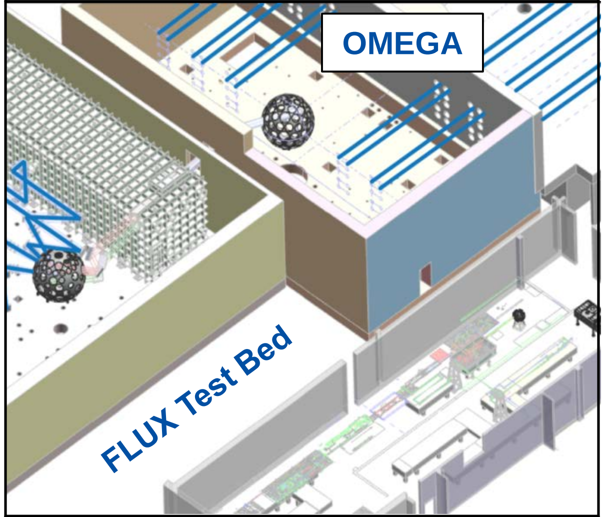
Test CBET physics understanding in a controlled environment

Fourth generation Laser for Ultra-broadband eXperiments (2018-2020)



Demonstrate laser technologies that would scale to OMEGA

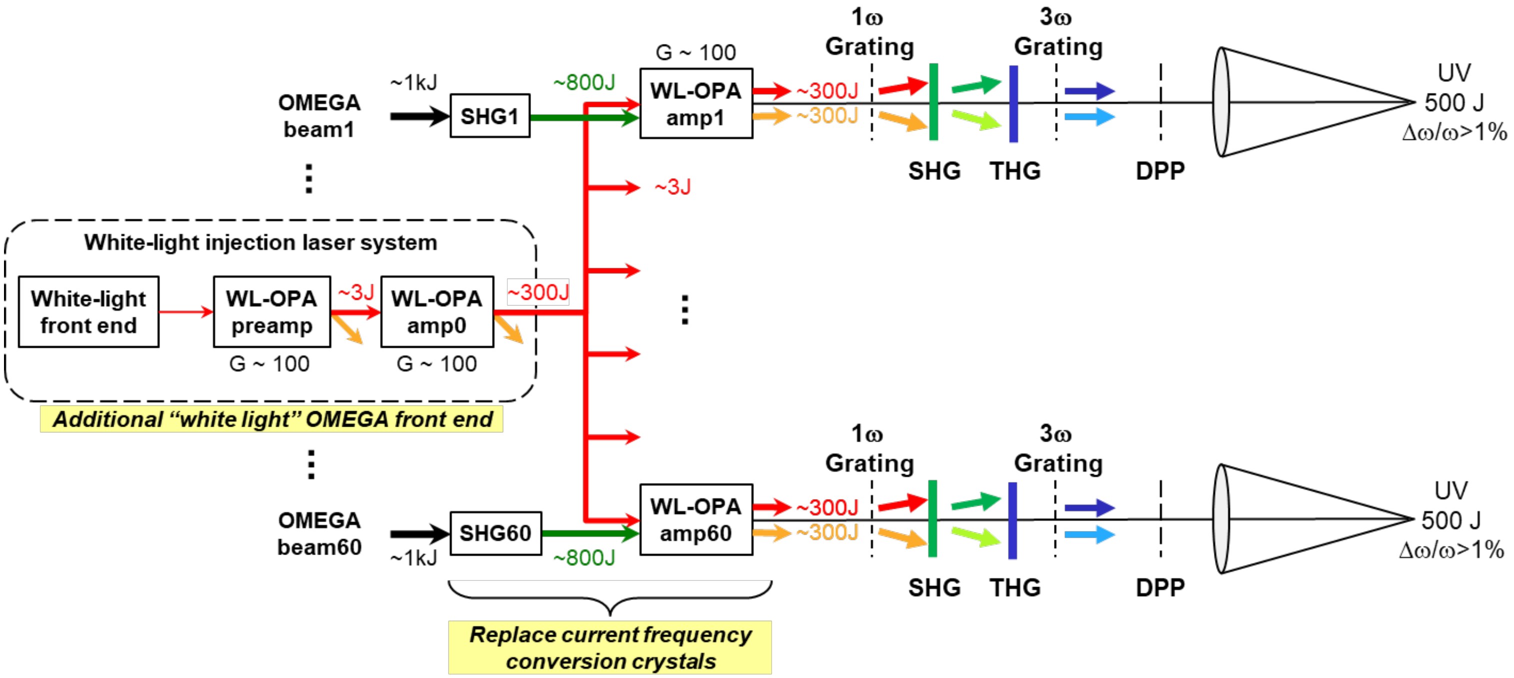
The FLUX laser will feed the OMEGA LPI Platform (2020-2023)



FLUX-p9 experiments will validate LPI modeling with bandwidth

*FLUX: Fourth Generation Laser for Ultra-broadband eXperiments

A conceptual layout for a "OMEGA FLUX-60" leverages the existing infrared laser system with few changes



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  - LLE is using its experience in CPA lasers to build a broadband test bed for demonstrating LPI mitigation using ultra-large bandwidth ($\Delta\omega/\omega>1\%$)

The unique combination of plasma physicists, laser scientists, and optical engineers at the LLE are enabling innovative solutions to laser-plasma applications

LID: Laser Indirect Drive
LDD: Laser Direct Drive
MagLIF: Magnetized Liner Inertial Fusion