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Fusion Power Associates
45th Annual Meeting and Symposium:
Progress, Challenges and Promise
Grand Hyatt Hotel
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Advancing the science and technology of laser fusion with excimers: the NRL program's unique capabilities, near-term objectives and future outlook*

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Plasma Physics Division
U.S. Naval Research Laboratory

So what exactly *is* an excimer laser?

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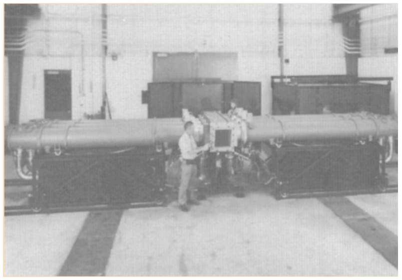
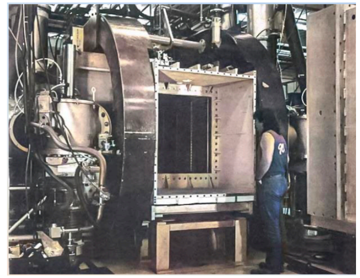
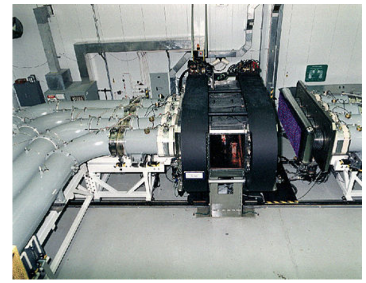


RAPIER (LLNL, 1979)
KrF, 25 J, 50 ns



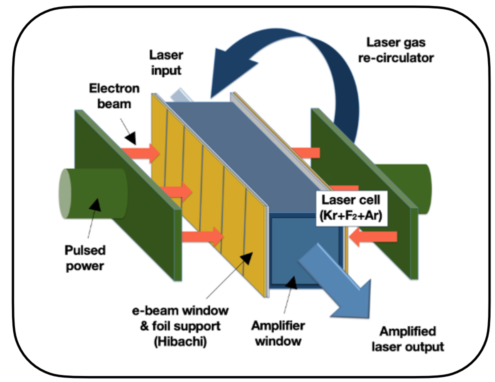
Aurora (LANL, 1986)
KrF, 10 kJ, 500 ns

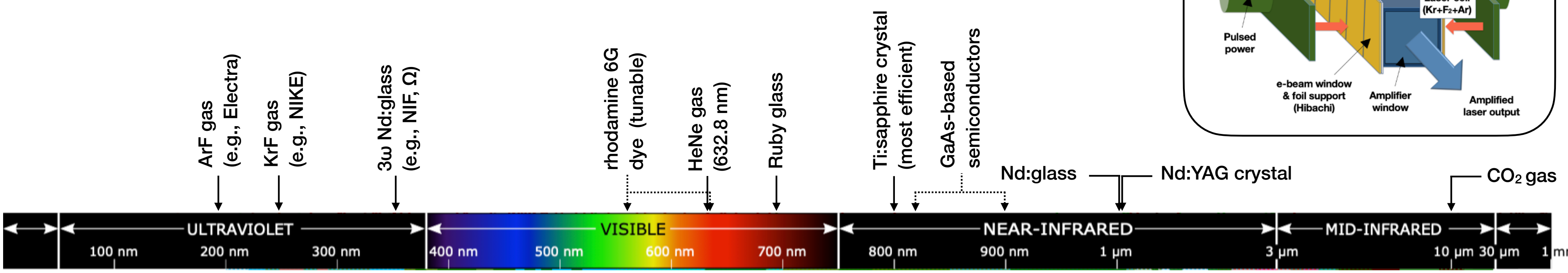


NIKE (NRL, 1995)
KrF, 3 kJ, 300 ns

- Rare gas-halide excimer lasers were discovered in the 1970s; “excimer” is a portmanteau of “excited dimer,” which refers to a diatomic molecule in an excited state
- Excimer molecules do not form chemical compounds under normal conditions, but form unstable compounds when they are in an excited state (such molecules then dissociate in the ground state producing laser light)
- Excimer wavelengths are < 360 nm and use a mixture of noble (e.g., He, Ar, Kr) and halogen (e.g., F, Cl, Br) gases
- Low-energy excimers, which are used in lithography, are pumped by electrical discharges; high energy ones, require pumping by **high-energy electron beams from high-voltage pulsed-power systems**

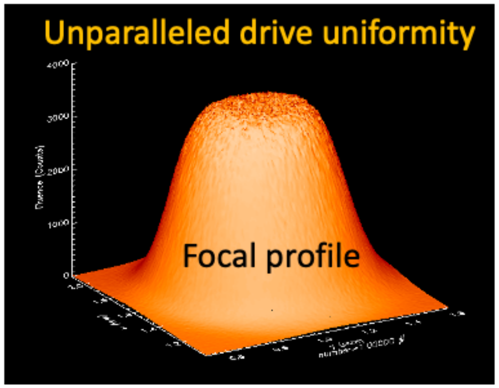
High-energy excimer lasers are pumped by electron beams

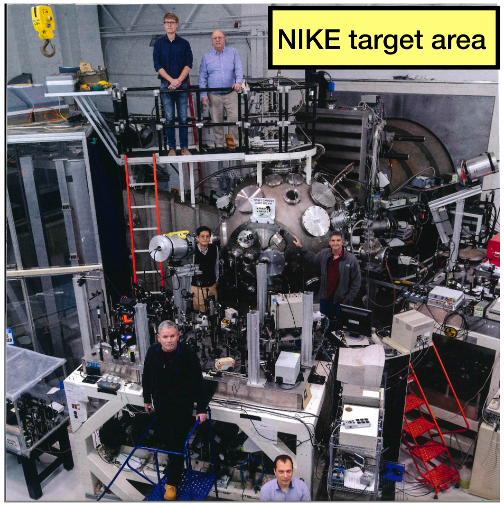




What is unique about NRL's NIKE laser-target facility and what is it good for?

- World's highest uniformity and deepest-UV multi-kilojoule excimer laser
- Drive uniformity without the complexity of a hohlraum
- High pressure drive without contamination from hard x-rays or hot electrons
- Advanced diagnostics: Monochromatic x-ray imaging, advanced spectroscopy, 1D and 2D VISAR; 5th harmonic probing
- Ideal experimental platform for studying a variety of HEDS subjects
- Uniquely suited for investigating multi-beam LPI with broad bandwidth
- Mid-scale facility with hands-on operation for workforce development





VISAR = Velocity Interferometer System for Any Reflector
HEDS = High Energy Density Science
LPI = Laser Plasma Instability

Highly-uniform laser drive and state-of-the-art diagnostics make NIKE well suited for focused experiments with broad ICF/IFE applications

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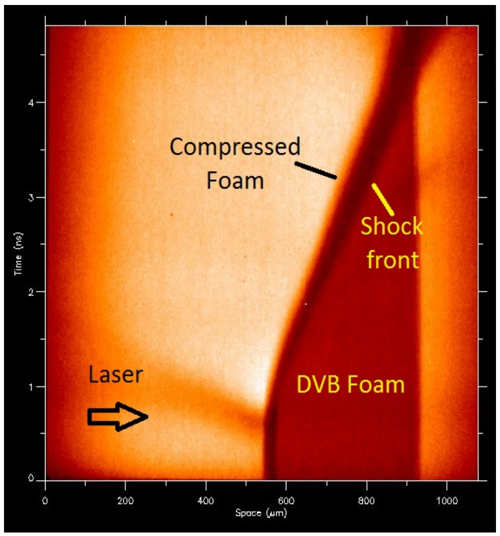
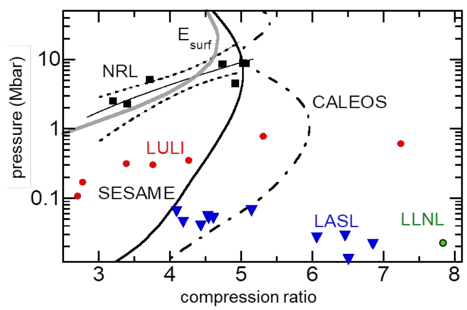
Foams are used in HEDS and IFE, but are challenging to model accurately



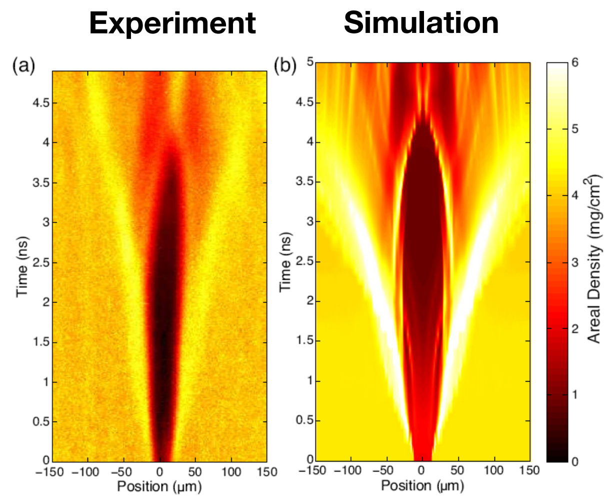


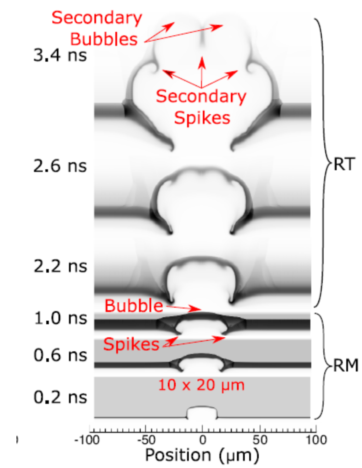
Y. Aglitskiy *et al.*, PoP **25**, 032705 (2018)

- Advanced x-ray imaging and NIKE's uniform drive allow unique platform for *absolute* EoS measurement of these materials

EoS = Equation of State

Pioneering study of isolated defects present in all laser-driven implosions

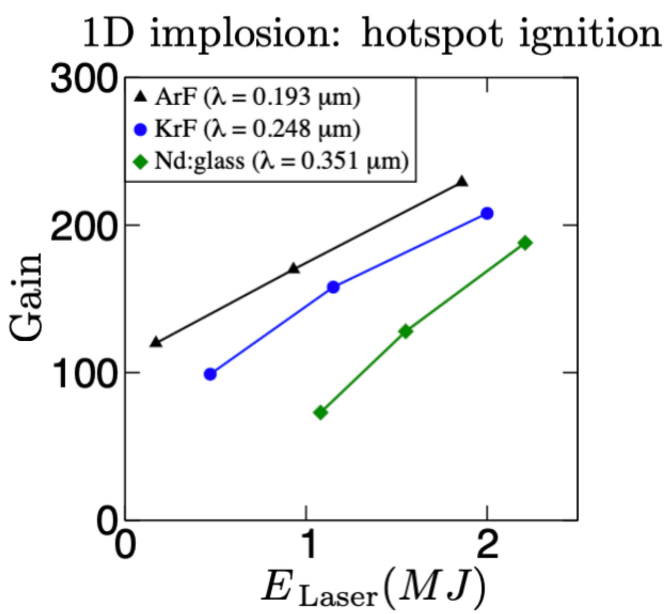


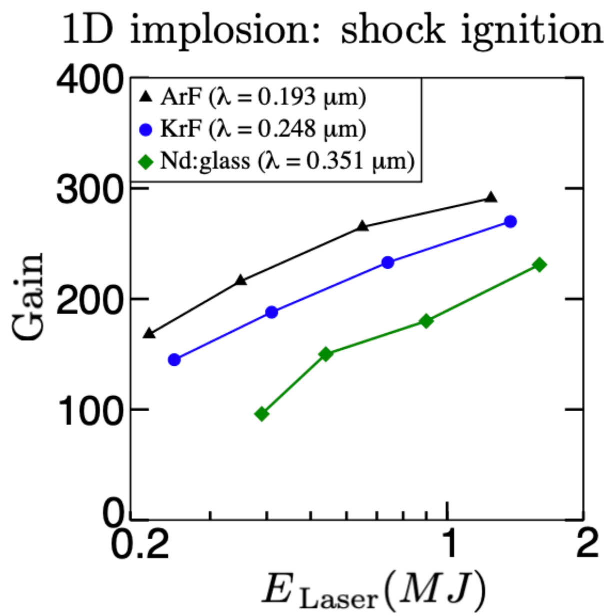


20μm-deep, 25μm-wide initial defect machined in-house using femtosecond laser

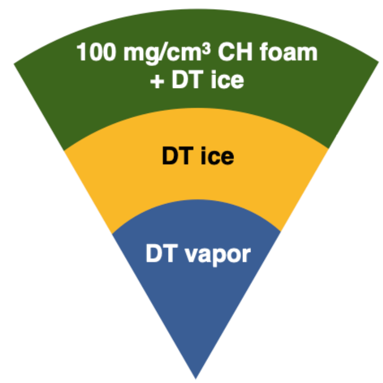
Zulick *et al.*, PRL **125**, 055001 (2020)
Zulick *et al.*, PoP **27**, 72706 (2020)
Velikovich *et al.*, PoP **27**, 102706 (2020)

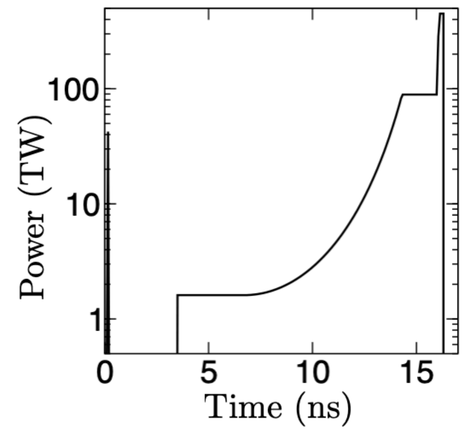
Simulations suggest high gains (> 100) are possible in conventional target designs using < 1 MJ of ArF laser light with zooming; even higher gains with shock ignition*





ArF Shock Ignition (SI) Design



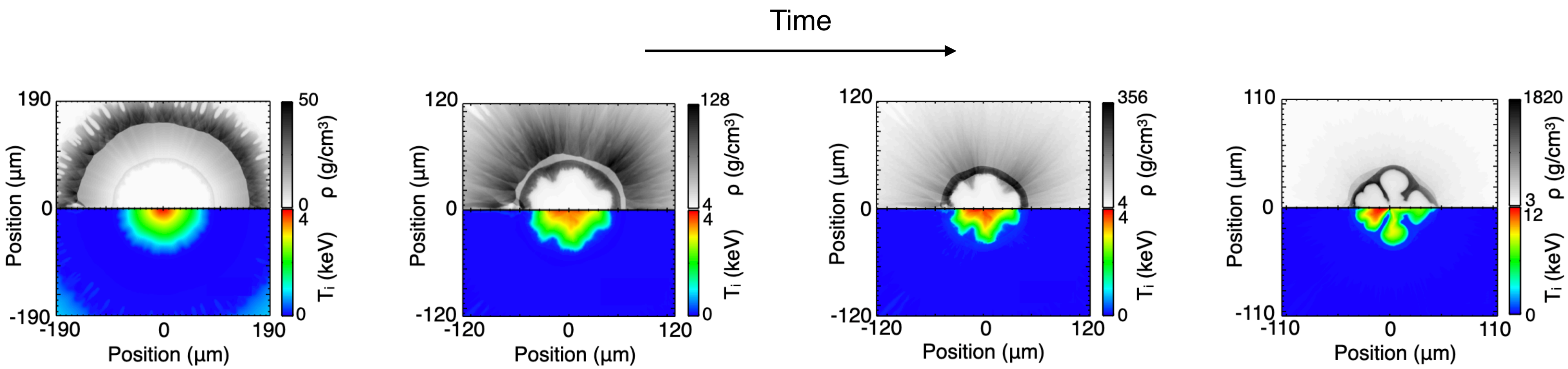


- **LPI effects were not included in simulations**

*R. Betti et al., Phys. Rev. Lett. **98**, 155001 (2007)

2D simulations* indicate an ArF laser can achieve target gains (>100) needed for laser fusion with sub-MJ drivers

Sample simulation of a 410 kJ ArF shock-ignited target design with 2 focal “zooms”



160x gain including effects of target imperfections

148x gain adding effects of laser imprint @ 5 THz ISI beam smoothing

*A.J. Schmitt, APSDPP 2021

Shorter wavelength, broadband laser light helps to suppress laser-plasma instabilities, allowing targets to be driven at higher pressures*

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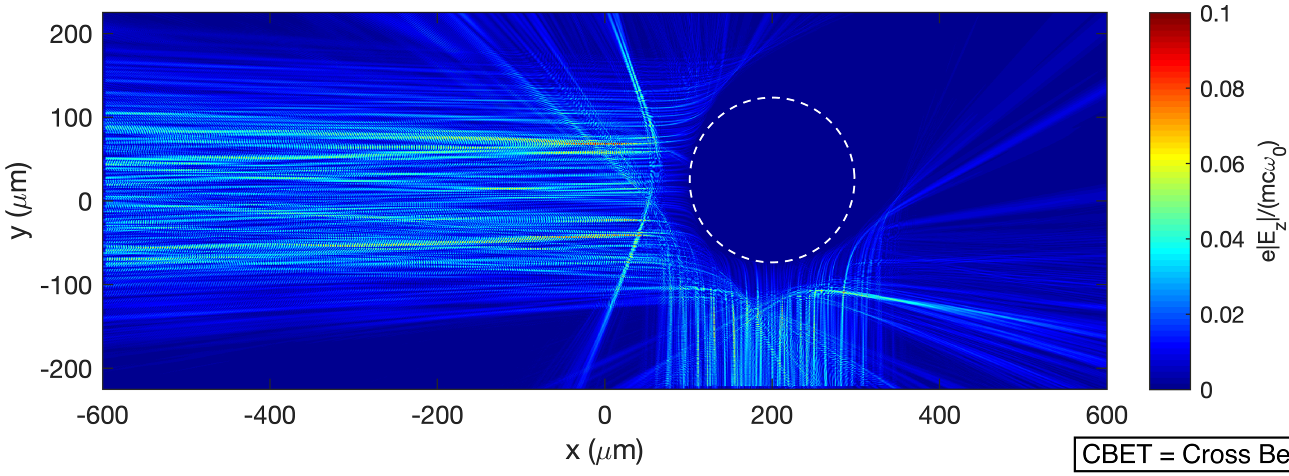
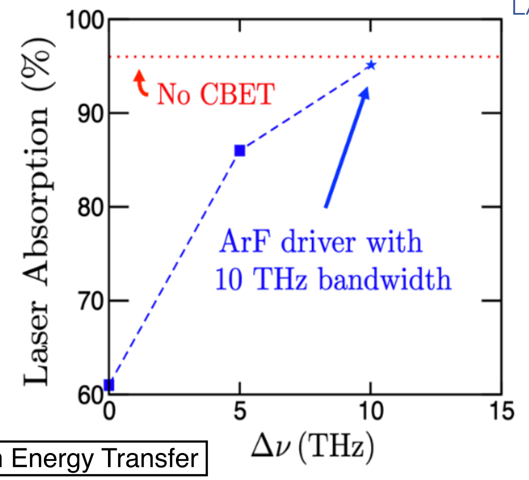
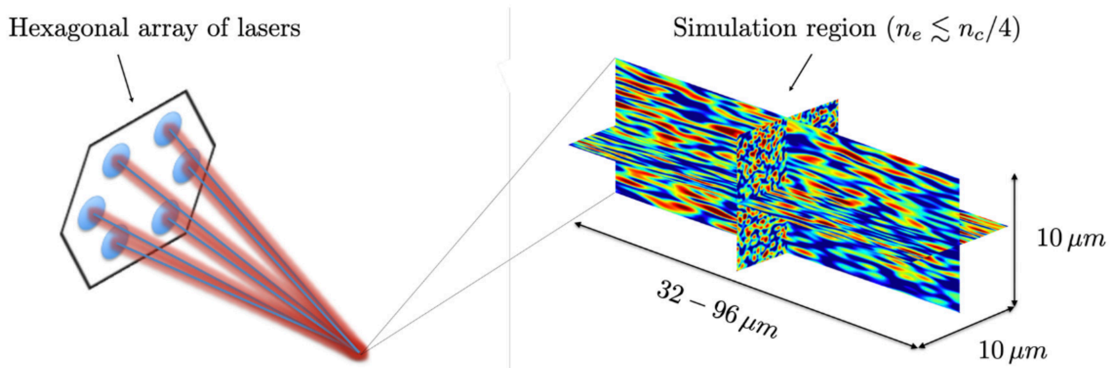
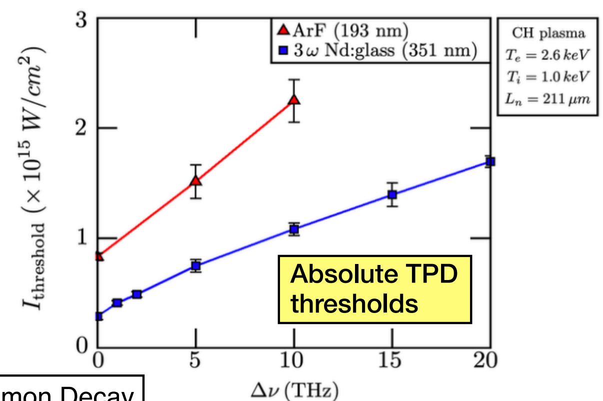




CBET = Cross Beam Energy Transfer





*Bates *et al.*, PoP **30**, 052703 (2023)

TPD = Two Plasmon Decay

Key excimer technologies demonstrated at NRL have leveraged NNSA, ONR, FES and ARPA-E funded programs

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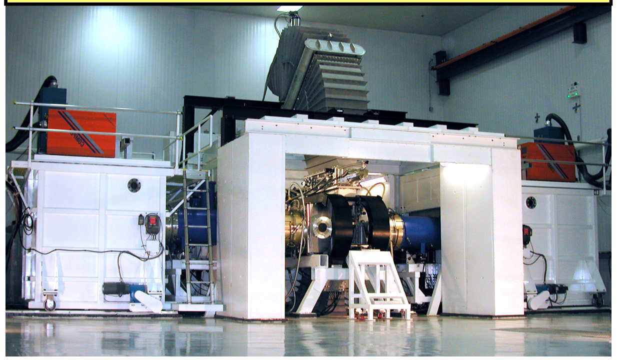
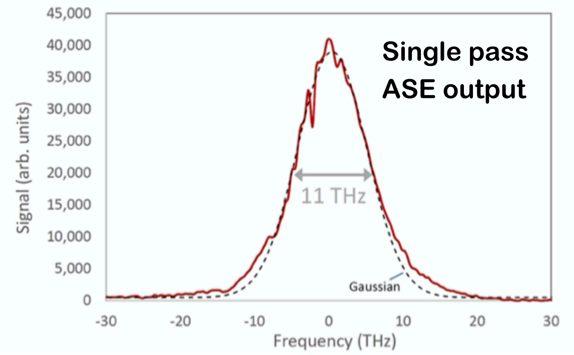
Electra ArF laser (world record: 200 J)



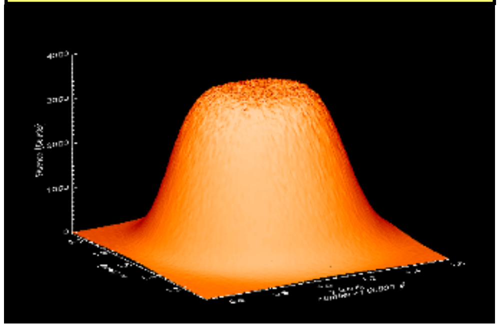
Demonstrated ~100k shot capacity (KrF)

Sethian *et al.*, IEEE Trans. Plas. Sci. **38**, 4 (2010)

Electra has produced 11 THz bandwidth

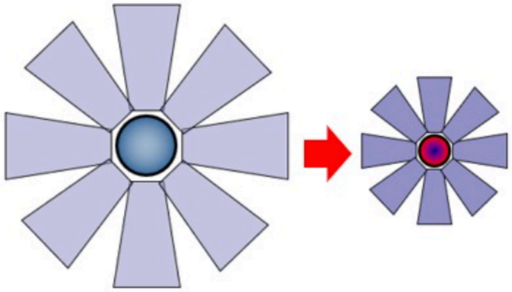


0.3% time-averaged RMS beam uniformity on NIKE

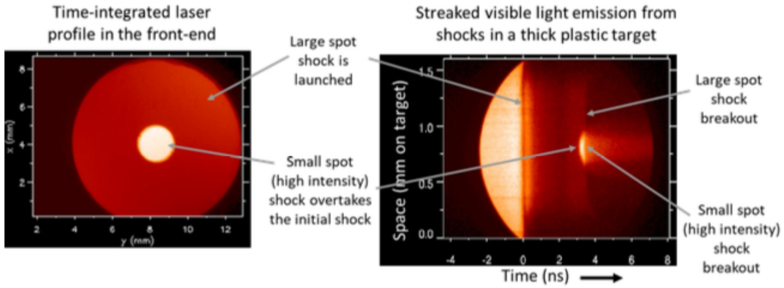


Deniz *et al.*, Opt. Commun. **147**, 402 (1998)

Focal zooming increases laser-target coupling and decreases CBET



Focal zooming demonstrated on NIKE



Keane *et al.*, RSI **84**, 013509 (2013)

We are collaborating with Xcimer Energy and the IFE RISE HUB; we are also exploring the possibility of joining LaserNetUS

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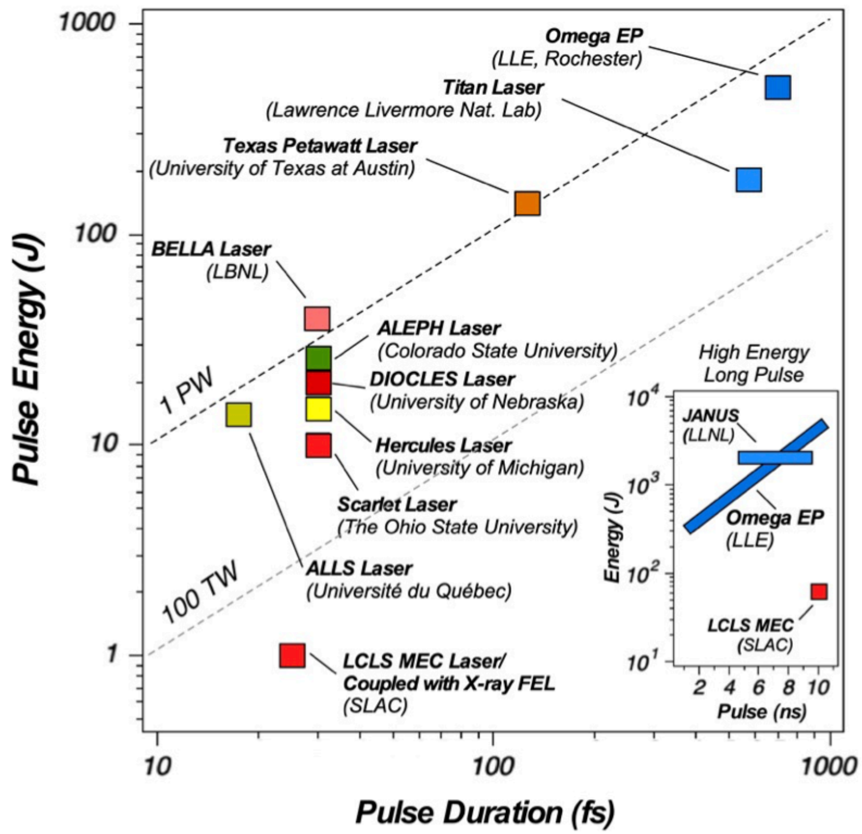
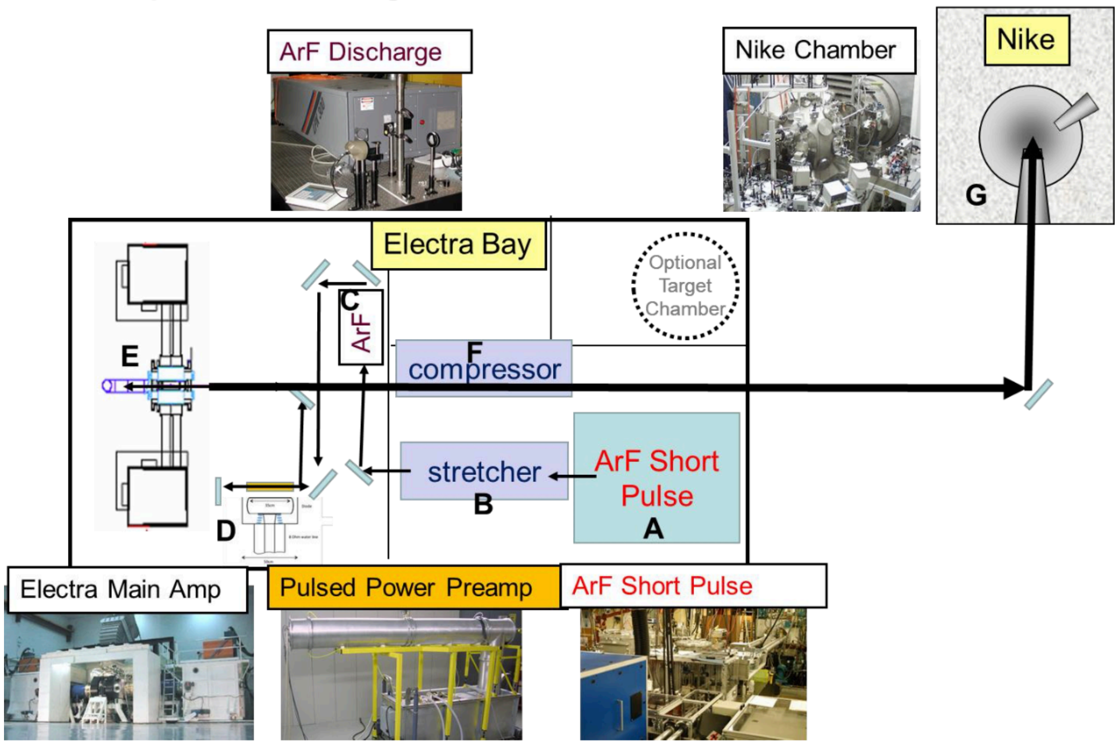
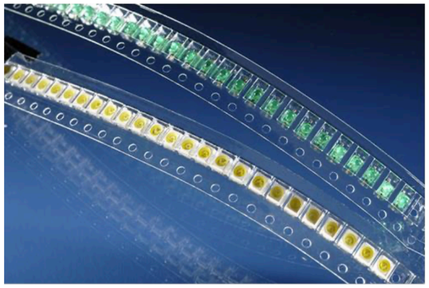
- LaserNetUS is comprised of 13 premier high-energy-density physics user facilities in the United States
- Majority of the facilities have a capability to near 1 PW of power. Some institutions have additional long pulse high-energy capabilities
- While pulse length on NIKE is much longer (typically several nanoseconds), the higher energy (2-3 kJ) and short laser wavelength (248 nm) could compliment capabilities of other LaserNetUS facilities



Another near-term goal is the development of an ultrashort rep-rated ArF laser



- The ArF laser has already demonstrated bandwidth in excess of 10 THz
- Straightforward modifications using chirped pulse amplification should enable pulse widths less than 33 fs with energies up to 10 J
- Estimated cost of this project is $7M
- Short ArF wavelength allows new capabilities such as the generation of gamma radiation with reduced pulse energy and peak power



Reels of planar targets can be fabricated to allow firing at 5Hz for 3 hours

A longer-term goal is to develop a 30 kJ ArF beam line

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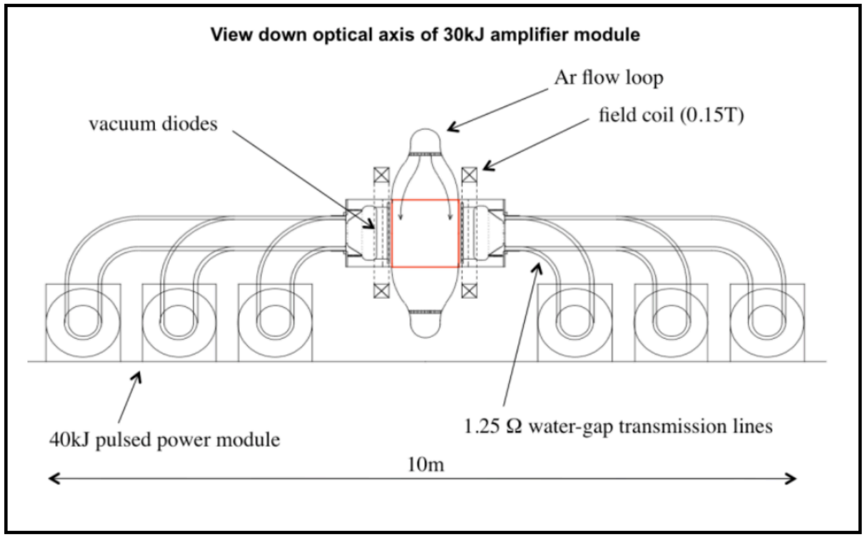
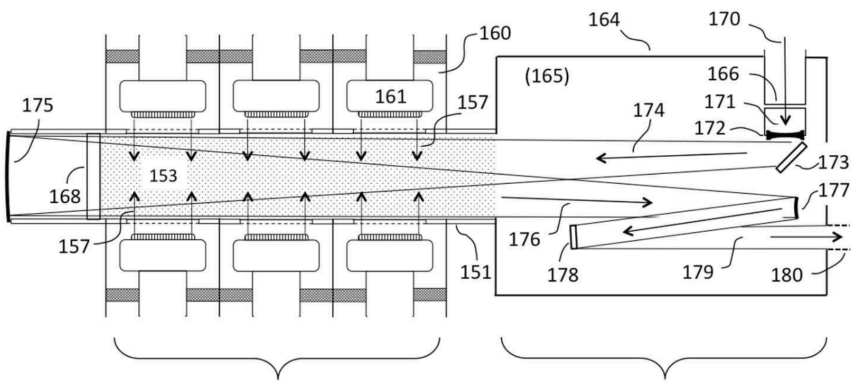


- The laser intensity in a large ArF amplifier is expected to exceed GW/cm^2
- Two-photon absorption in fused silica is a concern with rep-rate and long duration
- A "windowless" amplifier, as shown on the right, is a potential solution

- Construction of a larger, first-of-its-kind ArF module is attainable with present technology developed at NRL
- Nominally 100 beams, 2-4 ns pulse lengths, angular multiplexing, ISI beam smoothing and 10 Hz operation
- Estimated cost is approximately $100M (FY2024)
- Would enable testing of full shock-ignition intensities with large plasmas to test LPI at scale
- LaserFusionX is a natural partner for this project



Summary

The NRL program advances fundamental HEDS and is developing a promising path for IFE

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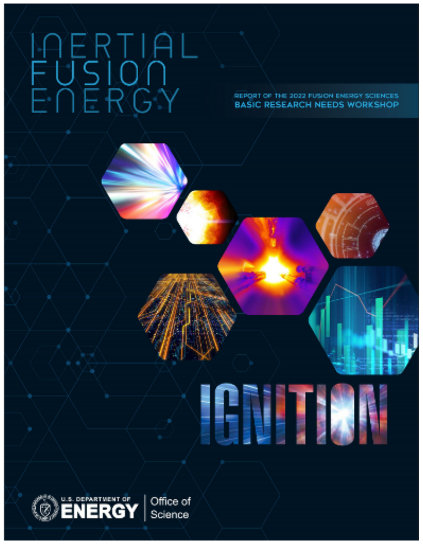
- NRL is the world-leading center for high-energy excimer lasers
- Flexible facilities capable of focused experiments, diagnostic development and code validation
- Balanced approach of external collaboration and internal research goals
- Offers a path to a future IFE facility using a sub-megajoule laser driver
- Enabled by superior target physics with excimer lasers and modern implosion designs
- Unique capabilities: short wavelength, unparalleled beam smoothing, broad bandwidth and zooming



Basic Research Needs Report (BRN 2023) identifies short wavelength, broadband drivers as enabling technology for IFE

NRL's unique facilities are avaiable for collaboration!

Extra Slides

New experimental platforms are being developed to support DoD-sponsored research

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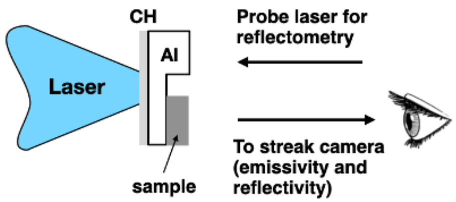
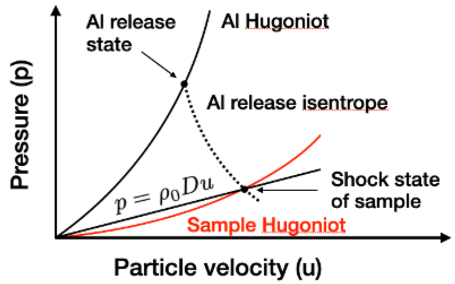
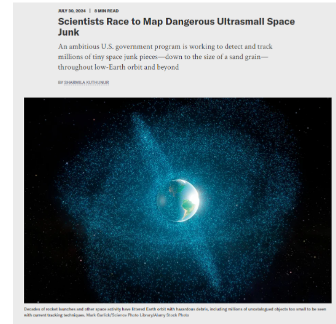
EoS of emerging materials



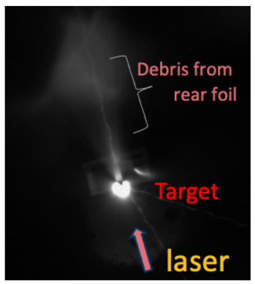


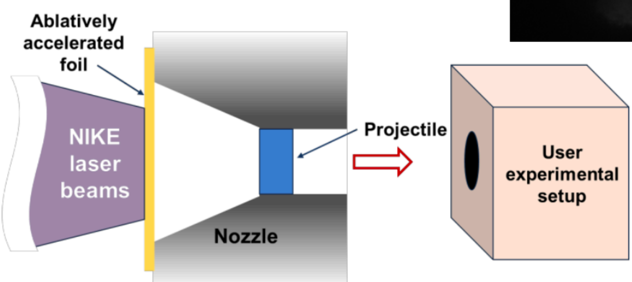

Scientists Race to Map Dangerous Ultrasmall Space Junk

An ambitious U.S. government program is working to detect and track millions of tiny space junk pieces—down to the size of a sand grain—throughout low-Earth orbit and beyond

EMP generation

- Higher higher velocities (10's km/s) and shot rates than gas guns





Detection of projectiles in plasmas