U.S. NAVAL RESEARCH LABORATORY

New pathways for ICF advanced at NRL

Fusion Power Associates Meeting

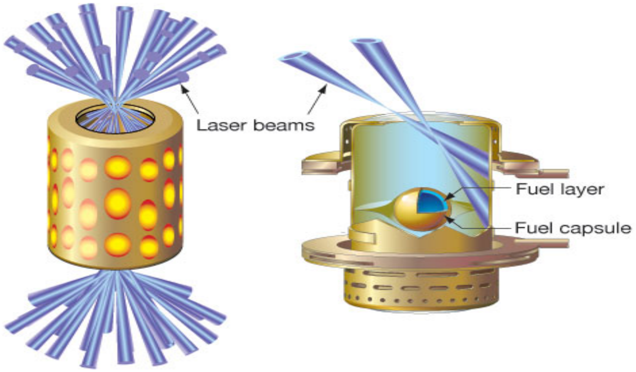
Washington DC

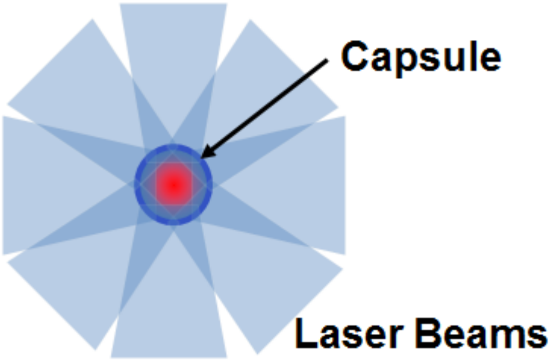
6-7 December 2016

Stephen Obenschain
Laser Plasma Branch
Plasma Physics Division

Work supported by DOE–NNSA

Common challenges to Direct and Indirect Laser Drive





Seeds for growth of high mode asymmetry

Target nonuniformity

Target nonuniformity
Early time laser imprint

Low mode drive asymmetry

LPI with high gas fills (SRS)
CBET at LIH
Hohlraum wall expansion with low gas fill
Beam control and target quality

Cross beam energy transfer (CBET)
Beam control and target quality

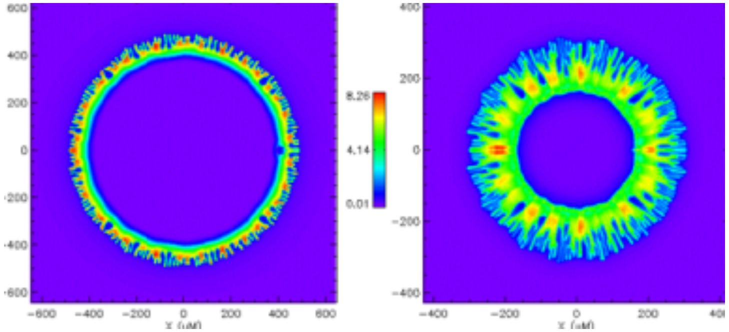
LPI can be main large loss mechanism & can cause unacceptable preheat of the target

Three focus areas of NRL ICF research

- Hybrid x-ray/direct drive approach using high-Z layers to mitigate laser imprinting.
- S&T to utilize laser bandwidth to mitigate LPI/CBET
- S&T of deeper-UV broader-native-bandwidth KrF and ArF excimer lasers as drivers next generation ICF facilities.

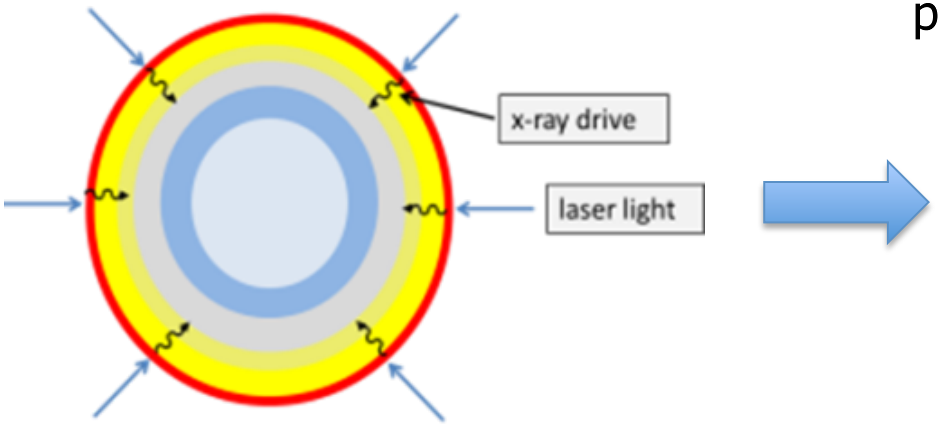
Mitigation of early time laser imprint is desired for direct drive implosions even with ISI/SDD smoothed beams

Imprint seeds hydro instability

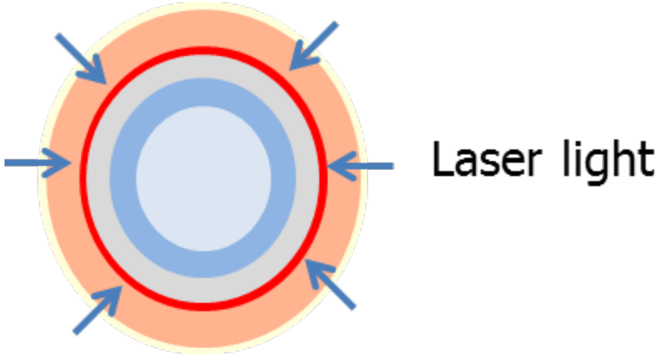


Hybrid x-ray direct-drive approach utilizing a pre-expanded thin high-Z overcoat

Initial X-ray drive



Later time direct drive when laser penetrates the high-Z plasma.

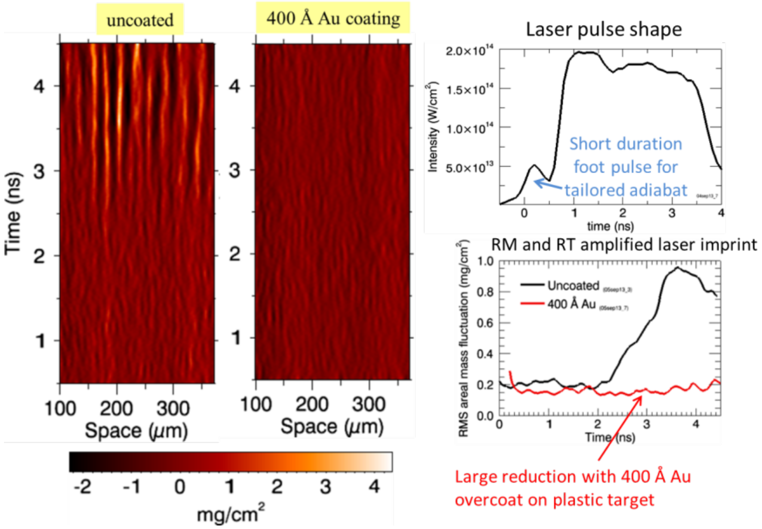


Spatial separation between laser absorption in the high-Z (Au or Pd) plasma and the x-ray driven pellet smooths imprint from laser nonuniformities.

Efficiency of direct drive retained!

Hybrid approach using high-z layers developed on Nike has been applied to Omega EP, with similar large reduction in laser imprint

Nike experiment

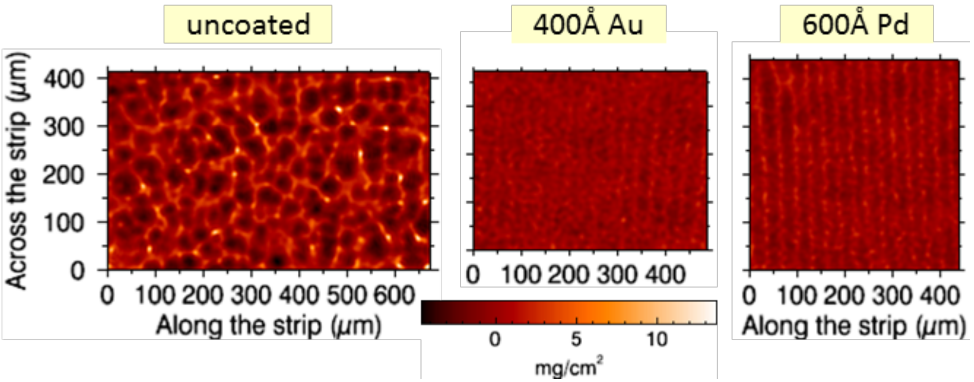


Large reduction with 400 Å Au overcoat on plastic target

Max Karasik, J. L. Weaver, Y. Aglitskiy, J. Oh, and S. P. Obenschain Phys. Rev. Lett. 114, 085001 – Published 26 February 2015

Omega EP experiment

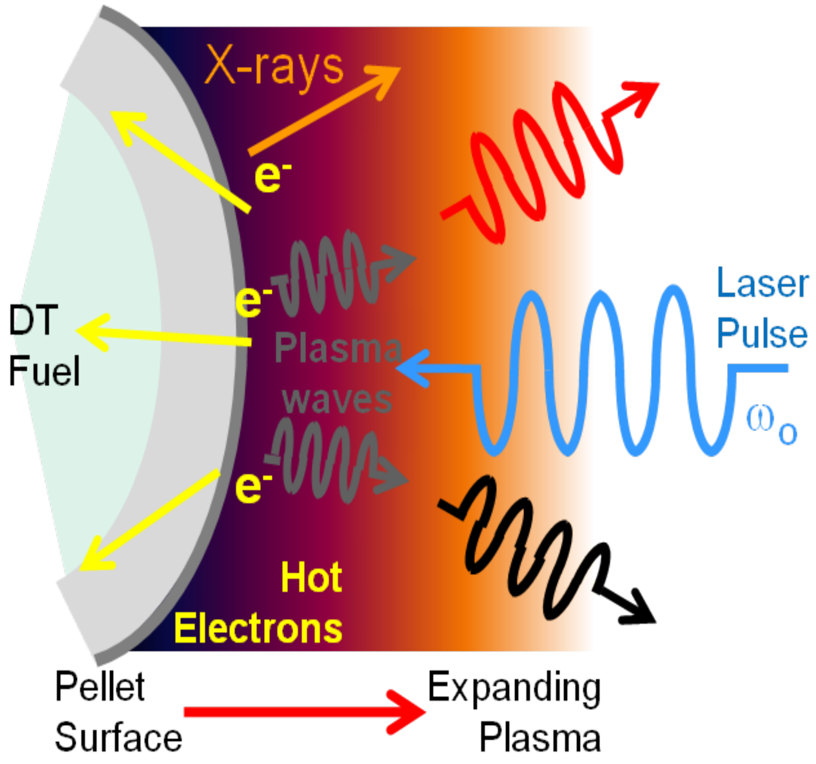
- Large imprint reduction with high-Z layer pre-expanded by a low energy x-ray prepulse.
- Phase plates but no SSD smoothing



with pre-imposed ripple (λ = 30µm, 1µm p-to-v)

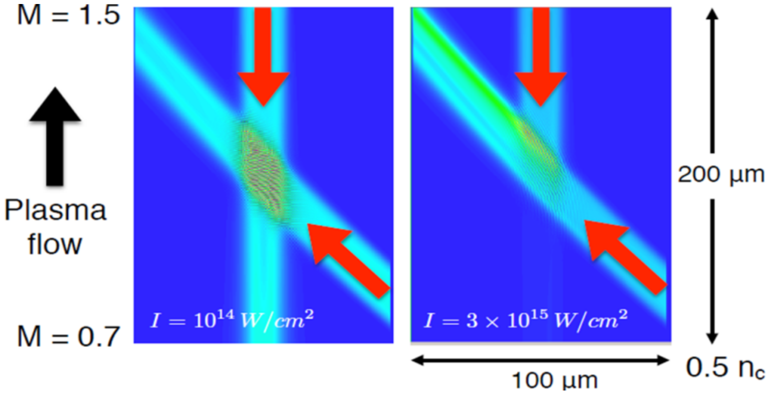
Plans underway to apply hybrid approach to Omega 60 implosions

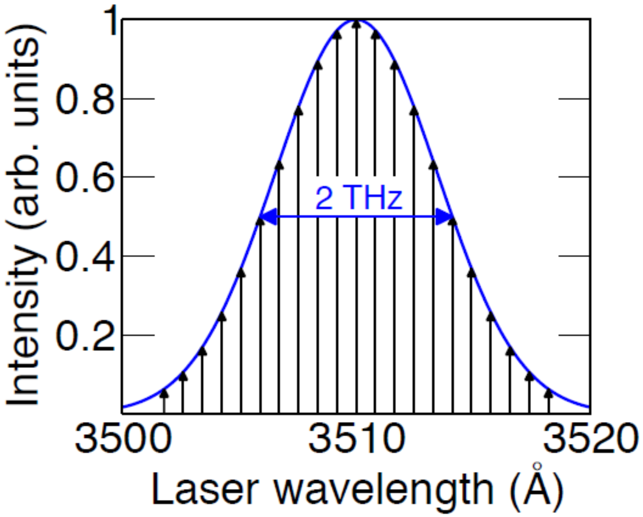
Mitigation of Laser Plasma Instabilities (LPI) and Cross Beam Energy Transfer (CBET) is also very desirable.

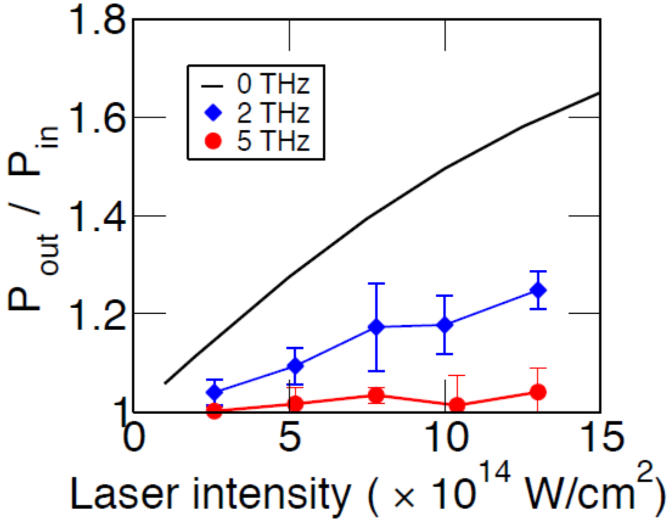


- **Shorter laser wavelength** increases the instability thresholds
- **Broad laser bandwidth** can disrupt the coherent wave-wave interactions that produce LPI and CBET

NRL simulations using LLE’s LPSE-CBET code indicate >2 THz laser bandwidths can suppress CBET



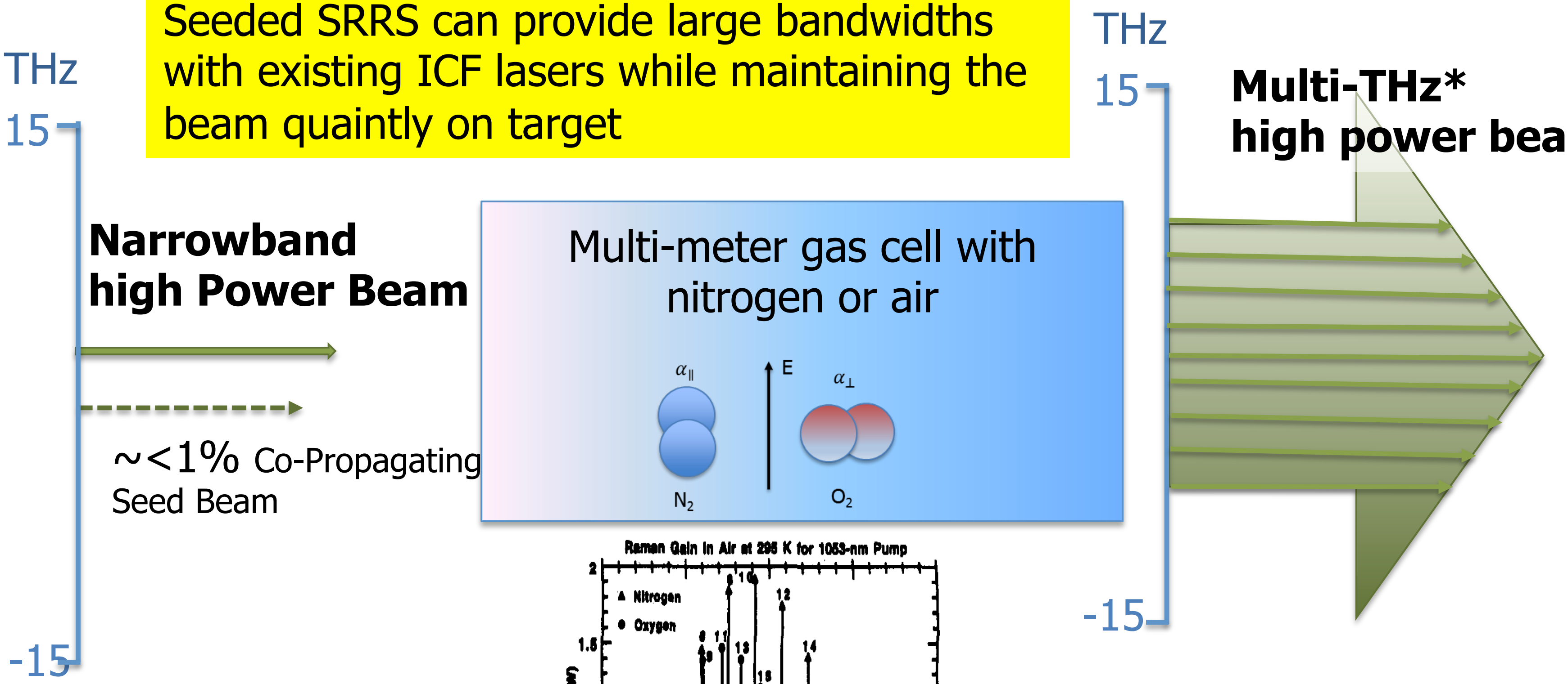




Jason Bates, IFSA 2017

Generation of laser bandwidth utilizing Stimulated Rotational Raman Scattering (SRRS)

Seeded SRRS can provide large bandwidths with existing ICF lasers while maintaining the beam quaintly on target



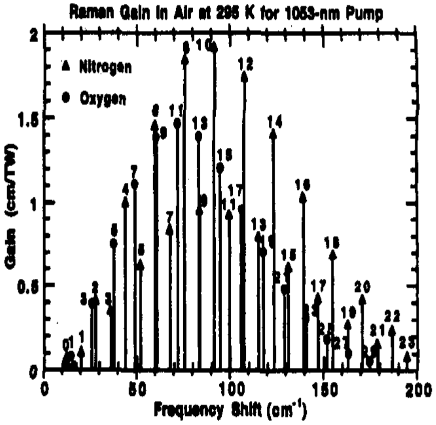
Narrowband high Power Beam

~<1% Co-Propagating Seed Beam

Multi-meter gas cell with nitrogen or air

Multi-THz* high power beam

O_2/N_2 SRRS spectrum, with THz line separation

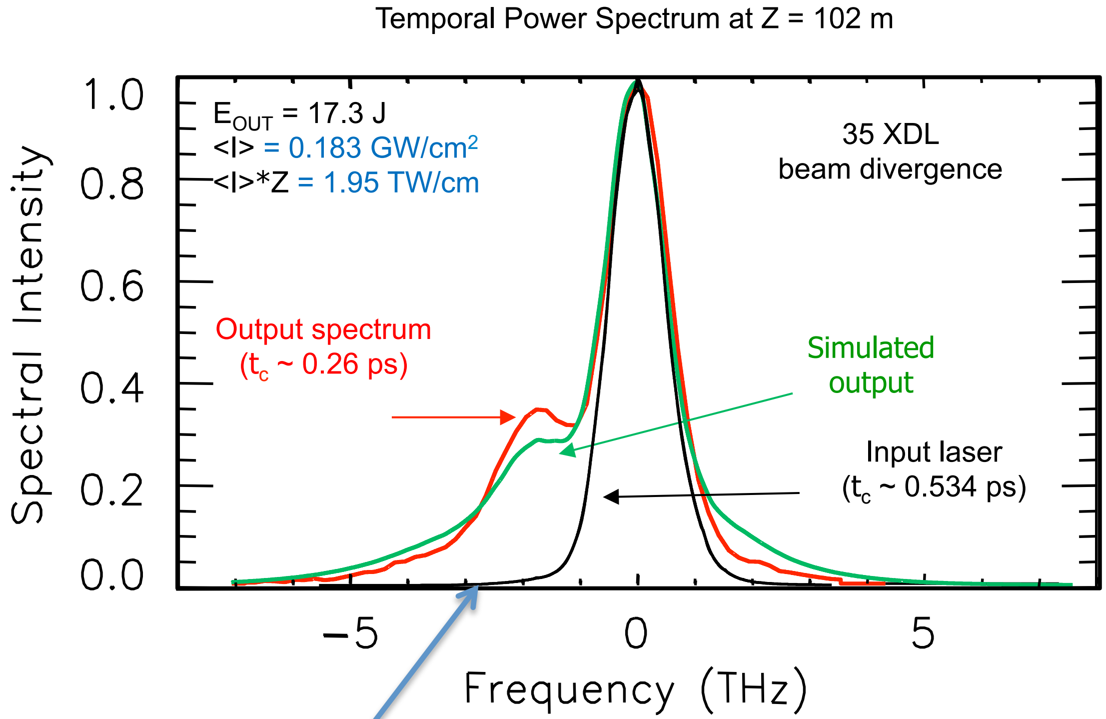


CThK57 Fig. 1 Calculated rotational Raman spectrum of N_2 and O_2 in air.

N. Kurnit (LANL) CLEO '96

* 8 THz with a frequency doubled Nd:glass laser demonstrated by D. Eimerl @ LLNL, PRL 1993

SRRS experiments on Nike are used to test code predictions



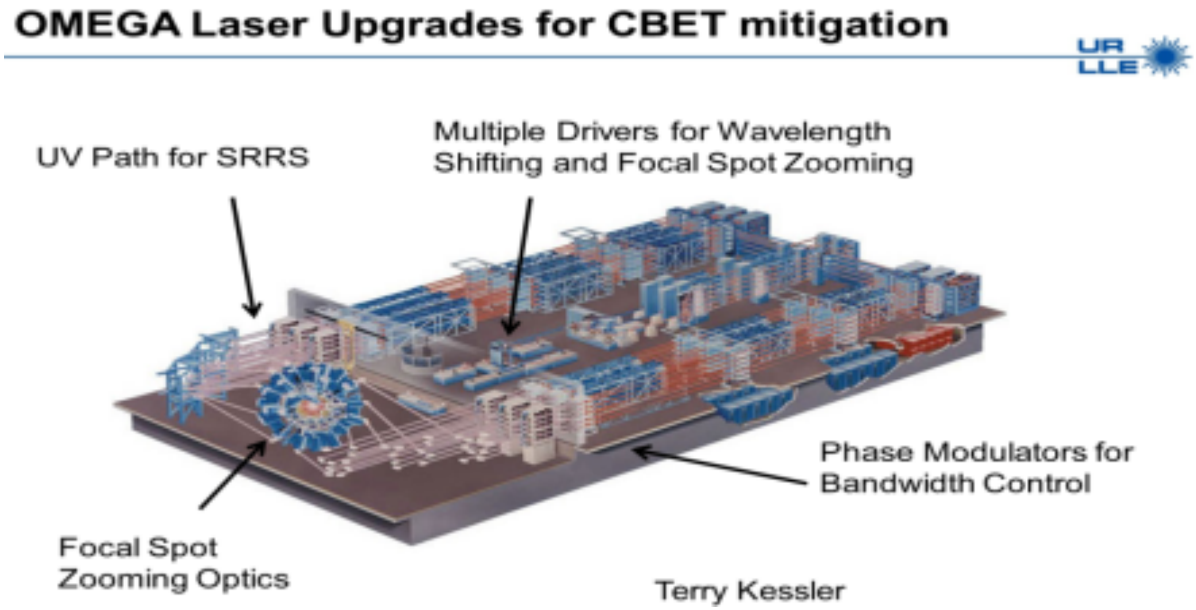
Spectral and far-field broadening due to stimulated rotational Raman scattering driven by the Nike krypton fluoride laser, J. Weaver, R. Lehmberg, et al. *Applied Optics* 2017
https://www.osapublishing.org/ao/abstract.cfm?uri=ao-56-31-8618

SRRS is self seeded by tail of the Nike beam's spectral distribution

Experiment with a frequency multiplied Nd:glass laser will begin in 2018 @ NRL

Path forward for bandwidth effort

- Complete basic S&T for SRRS induced bandwidth 2018-2019
- Define bandwidth needed to suppress LPI/CBET via simulations
- Install SRRS on a single high energy (~500 J) Nd:glass laser beam(s) to test bandwidth effects on LPI/CBET (351 nm on Omega and 527 nm on Nike)
- Apply to Omega 60 for direct drive and consider application to NIF indirect drive.



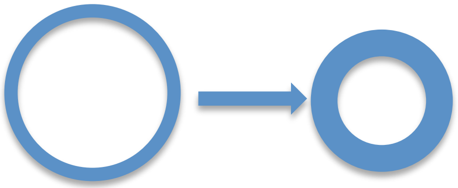
OMEGA Laser Upgrades for CBET mitigation

Terry Kessler

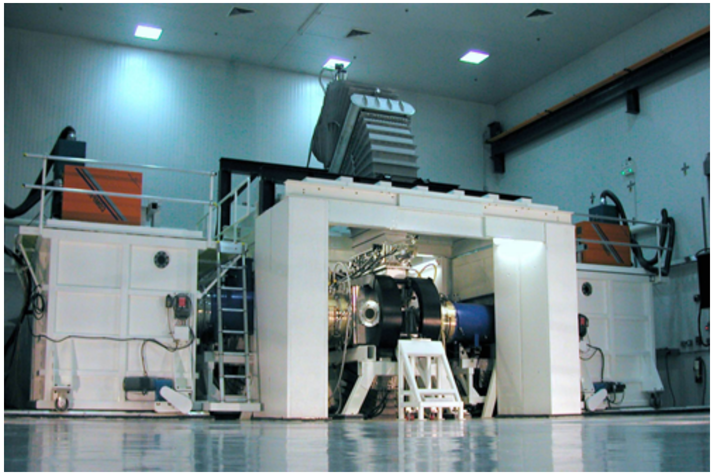
KrF and ArF Excimer lasers would be very attractive laser fusion drivers for a next generation ICF facility

- Deeper UV – 248 nm for KrF and 193 nm for ArF allows higher ablative drive pressure (P_{ab})
- Easy to zoom the focal diameter
- Broader native bandwidth (~3 THz for KrF) (~ 5 THz for ArF)
- Gas laser media is easier to cool allowing higher shot rates

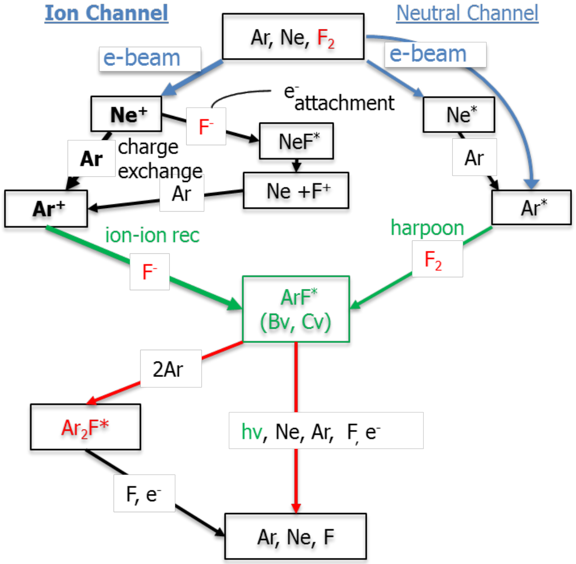
Higher P_{ab} allows lower aspect ratio pellets



NRL 6.1 funded effort will advance the basic physics of E-beam pumped ArF laser using the Electra facility



Modify NRL Orestes kinetic code for ArF and test against experiment.



Ion Channel

Neutral Channel

Ar, Ne, F_2

e-beam

e-beam

Ne^+

F^-

e^-attachment

Ne^*

NeF^*

Ar

charge exchange

Ar

$Ne + F^+$

Ar

Ar^+

Ar^*

ion-ion rec

harpoon

F^-

F_2

ArF^* (Bv, Cv)

2Ar

Ar_2F^*

hv, Ne, Ar, F, e^-

F, e^-

Ar, Ne, F

Perspectives on Pathways and Progress

NRL PPD

We need to advance fundamentally new approaches to laser ICF that reduce the technological and physics challenges!