Fusion Development Strategies

More Robust Approaches to laser ICF

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NRL supports strategy to exploit capabilities of NNSA large facilities (NIF, OMEGA and Z)

NRL PPD

Develop **physics** base and approaches for later decisions

Indirect drive

- How to overcome capsule and hohlraum physics challenges with limited drive energy.

  (e.g. near vacuum hohlraum and HDC capsules)

Direct drive (more energy on capsule)

- 100 Gbar OMEGA goal
- Determine technical, physics and cost challenges for implementing symmetric direct-drive on NIF

Develop MagLIF physics base – pulsed power drive and laser preheat

NRL ICF researchers designed, fabricated and delivered the Virgil X-ray Spectrometer in collaboration with the NIF diagnostics team

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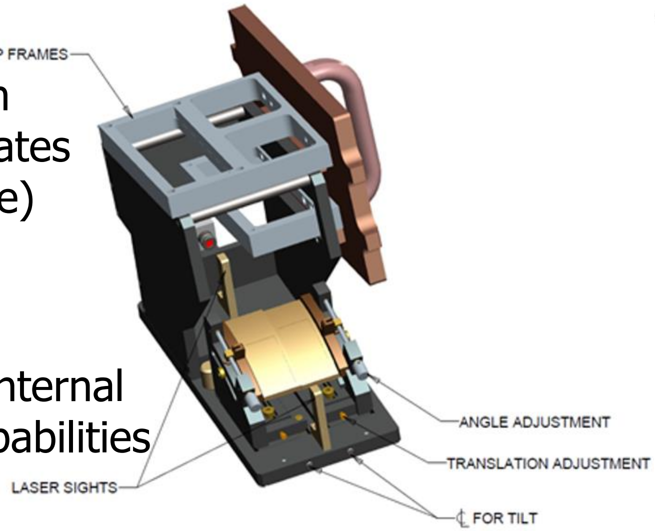
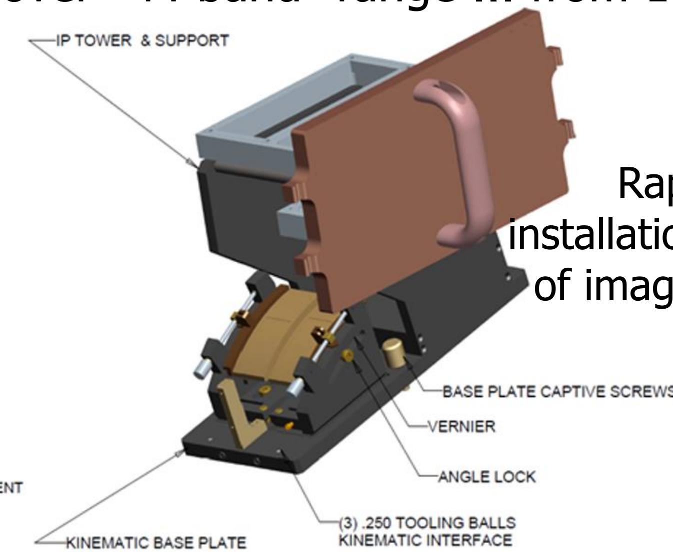
Two channel instrument to record spectra over "M-band" range ... from 1.5 to 6.0 keV

Current design uses image plates (could upgrade)

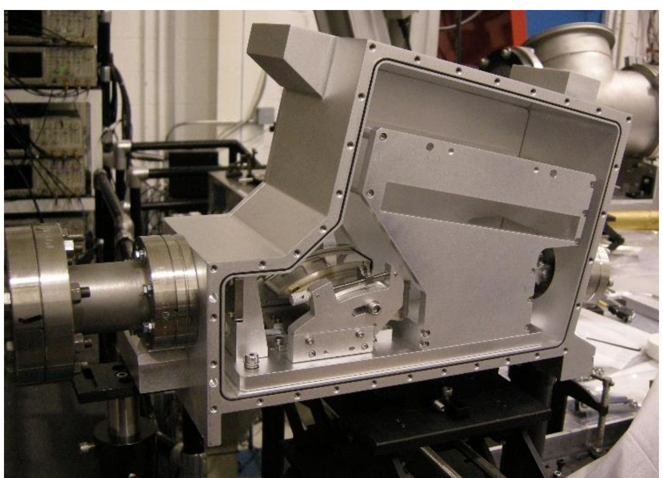
Incorporates internal alignment capabilities



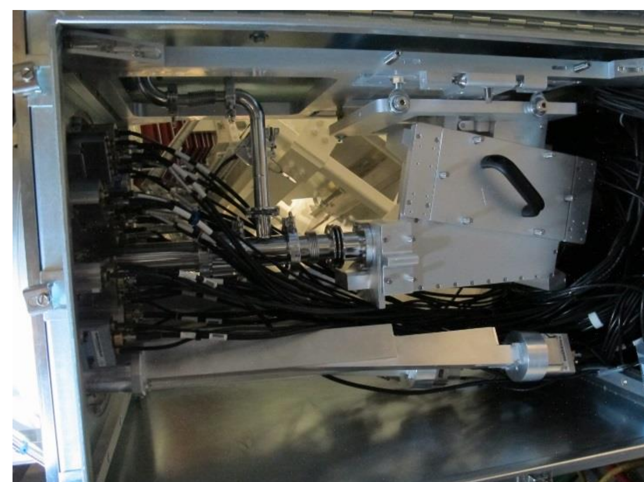


Rapid and reliable installation and removal of image plate holders

Tested at Nike KrF Laser (NRL)



Installed on Dante center port (NIF)



Virgil low-Z spectra obtained on Nike. We hear that it provided similar high quality spectra on NIF

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Nike Laser Parameters:

248 nm center wavelength

44 Main beams, 40 J/beam, 0.4 & 4 ns pulses

Small spot: 375 μm FWHM

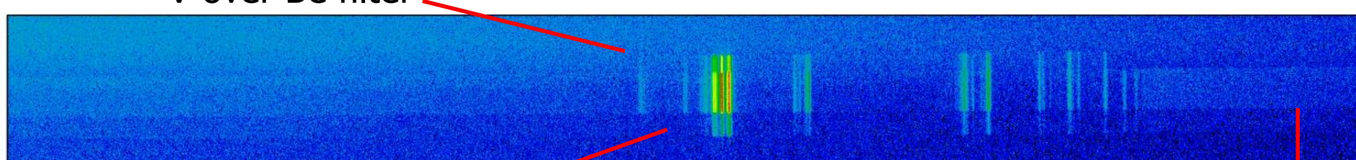
I_{laser} range: 1-9x10^{14} W/cm^2

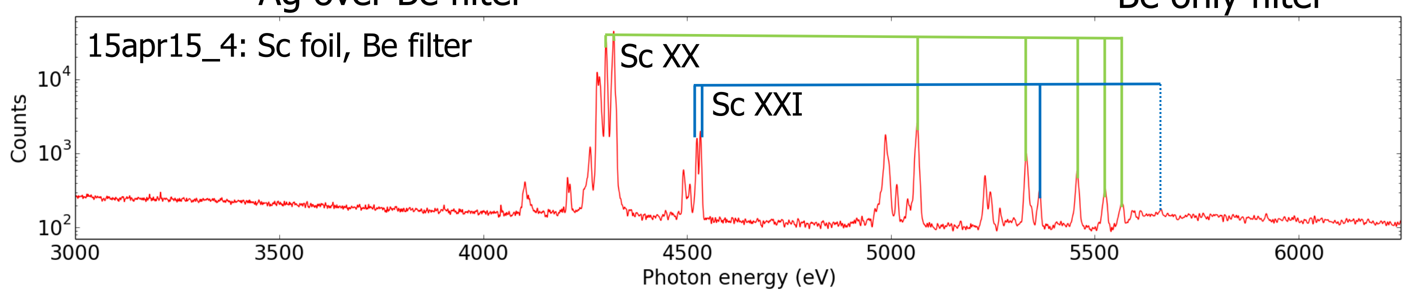
KAP channel: 1.5-3.0 keV

Co target, 4.2x10^{14} W/cm^2

Quartz channel: 3.0-6.0 keV

Sc target, 8.8x10^{14} W/cm^2





Path to more robust laser ICF – **wider and deeper**

(wider laser bandwidth and deeper UV)

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Laser Bandwidth (for all approaches)

- Extreme bandwidths (multi-THz) should help suppress parametric laser plasma instabilities that limit laser intensity and ablation pressure.
- Can we obtain such bandwidths with existing glass and excimer laser technologies?
- Properly implemented Stimulated Rotational Raman Scattering (SRRS) in a gas so far looks promising.

Deeper UV

- Increases threshold for LPI and hydrodynamic efficiency.
- Increased ablation pressure and mass ablation rate would reduce threat from hydro-instability in direct drive.
- Higher preheated gas density for MagLIF

Microwave-plasma interaction experiments at UCLA & UCD showed extreme driver bandwidth suppresses instability.

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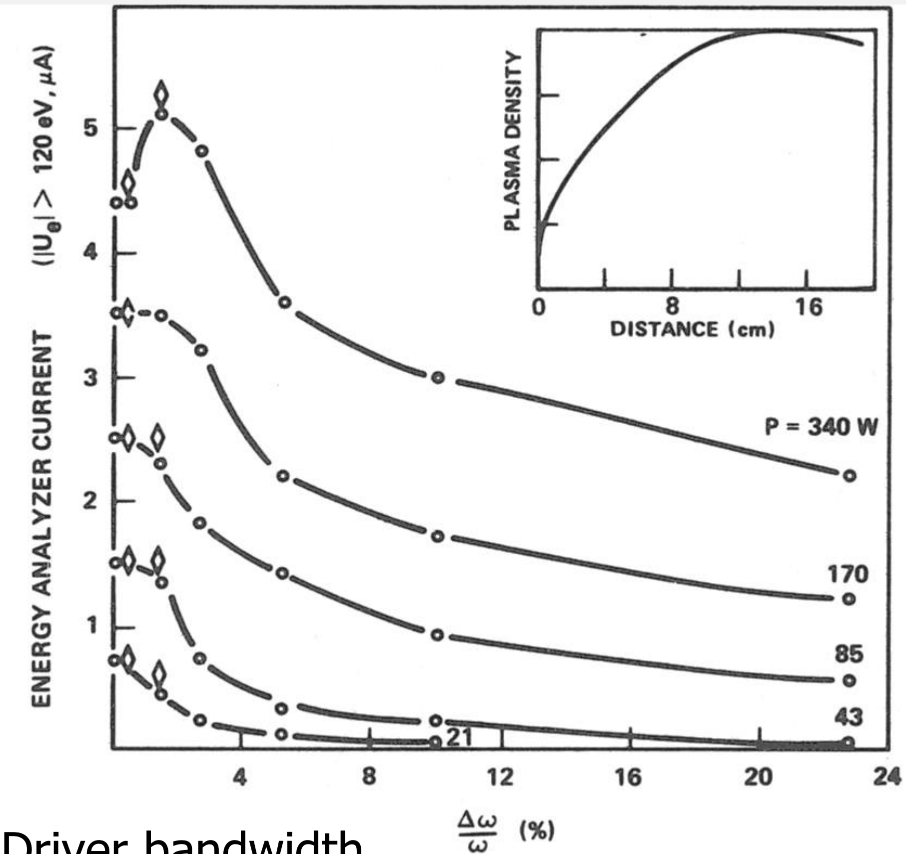
Hot electrons produced by parametric decay instability vs driver bandwidth

Hot e^-



Driver bandwidth

Reduction at powers 16x instability threshold

Complete suppression at powers a few times instability threshold

UCLA microwave-plasma interaction experiment,
S. P. Obenschain and N.C. Luhmann Jr., App. Phys, Lett, 30,452 (1977).

Simulations of $n_{ec}/4$ instability utilizing a plasma fluid code indicate bandwidths above 3 THz reduce growth

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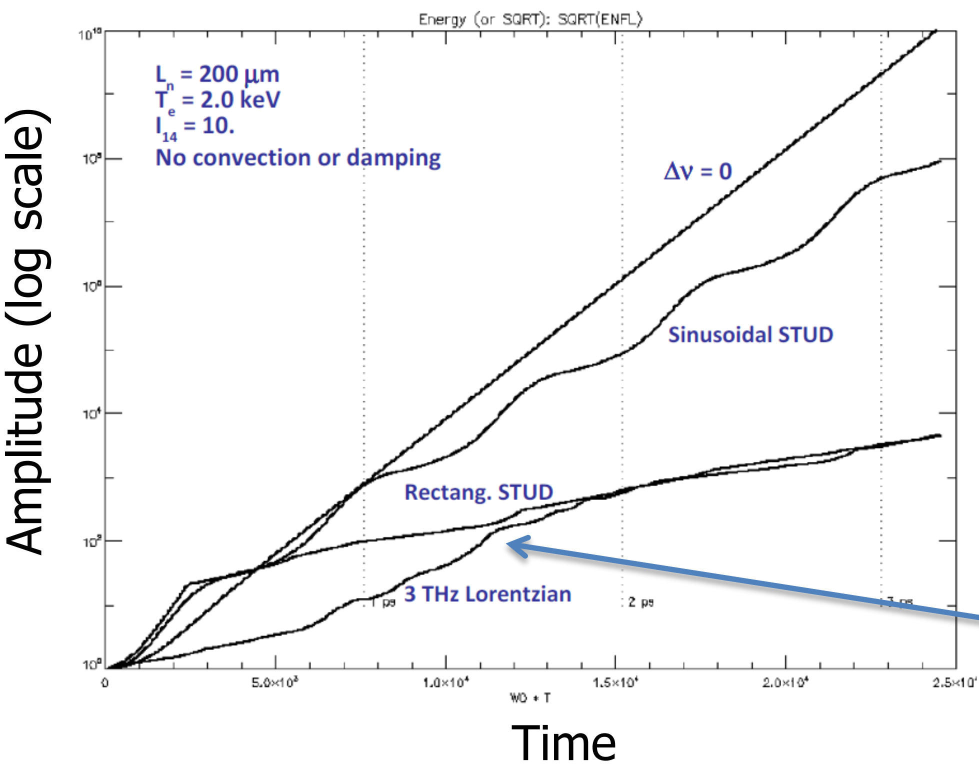
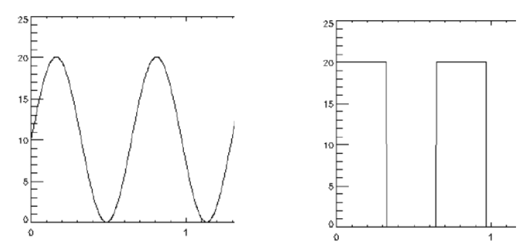
Research effort is exploring & comparing means to mitigate instability including laser bandwidth, laser incoherence via beam smoothing (ISI & SSD), and use of STUD pulses.



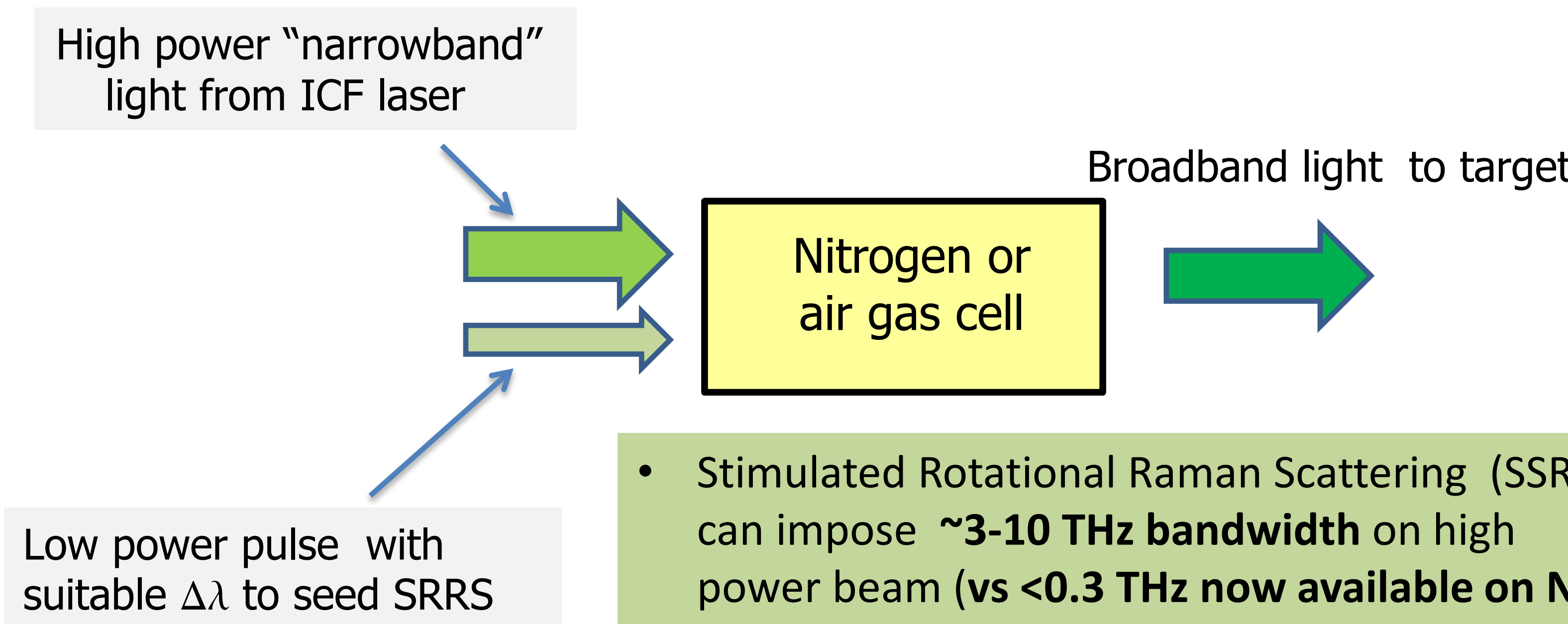
Simulation of absolute instability growth with fluid code, R. Lehmberg

0.32 ps sin. and rect. "STUD"



Both 3 THz bandwidth and 0.32 ps rectangular STUD pulses reduce growth

SRRS should be able to provide bandwidths >3THz



- Stimulated Rotational Raman Scattering (SSRS) can impose **~3-10 THz bandwidth** on high power beam (**vs <0.3 THz now available on NIF**)
- Low power seed pulse ensures that spectrally broadened laser light has suitable focusing characteristics on target.

An advanced simulation code for SRRS developed at NRL is in agreement with observed SRRS spectra using a Nike KrF beam

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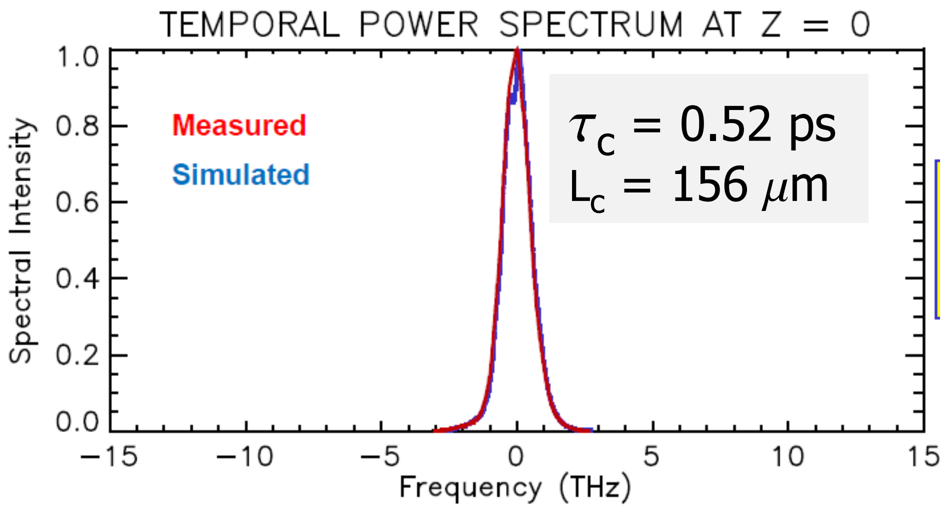
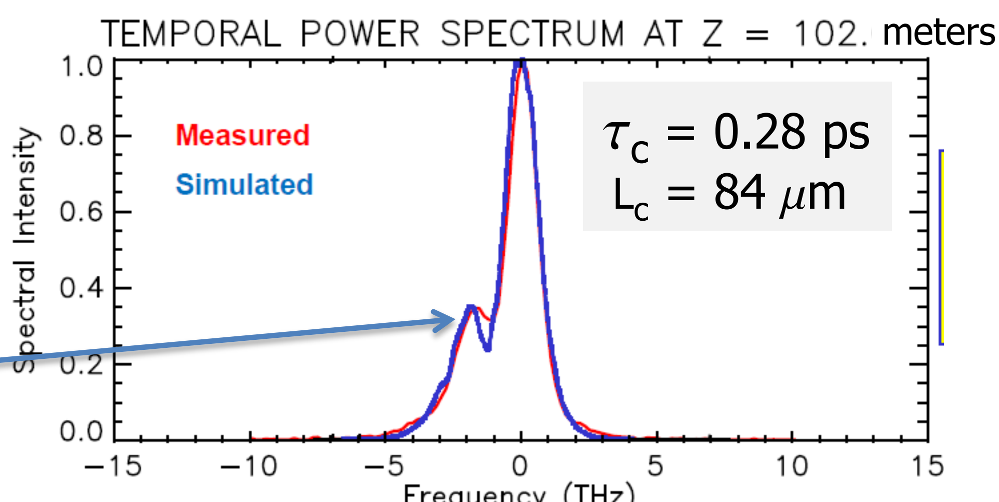
Native KrF beam bandwidth (~1 THz FWHM) and after traversing 102 meters in air



coherence time = τ_c
coherence length = L_c
$L_c = c \times \tau_c$



KrF bandwidth is sufficient to "self seed" SRRS

At twice the intensity, the simulations show additional broadening with a coherence time (τ_c) down to 0.16 ps

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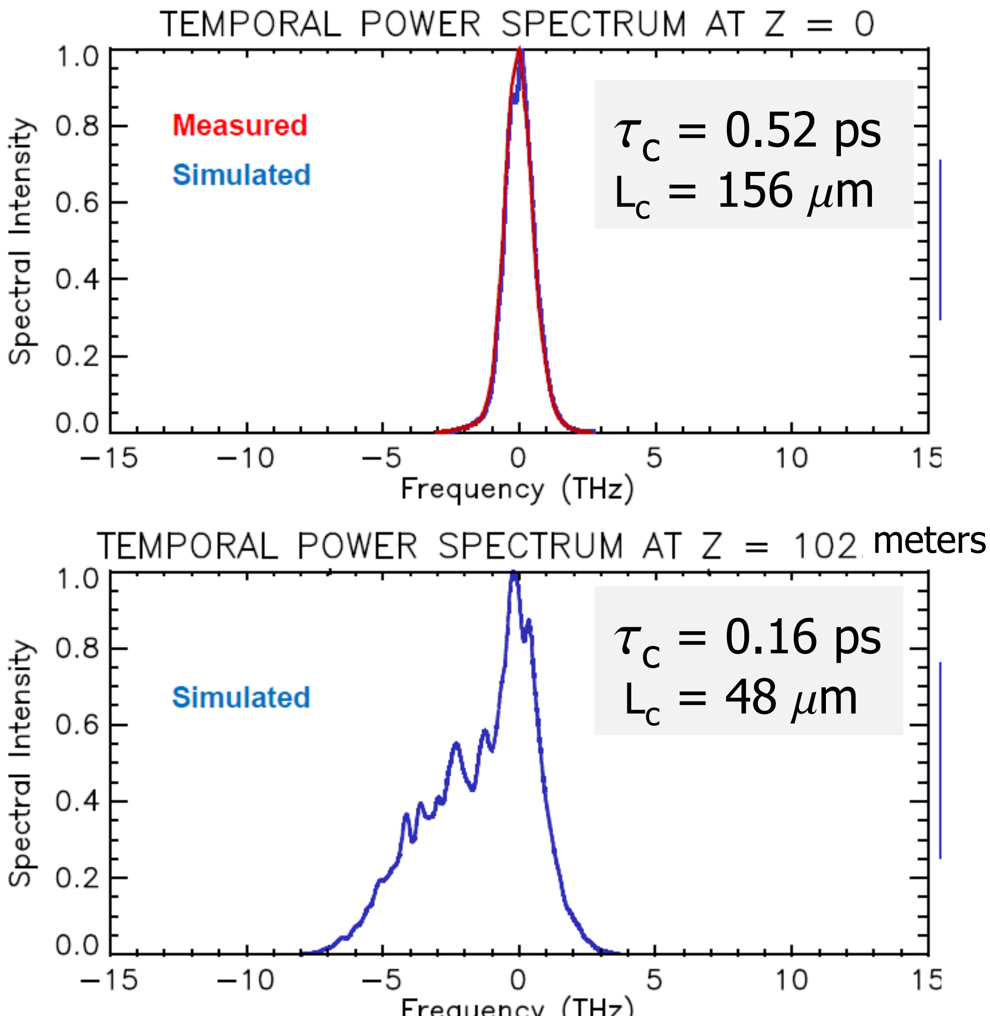
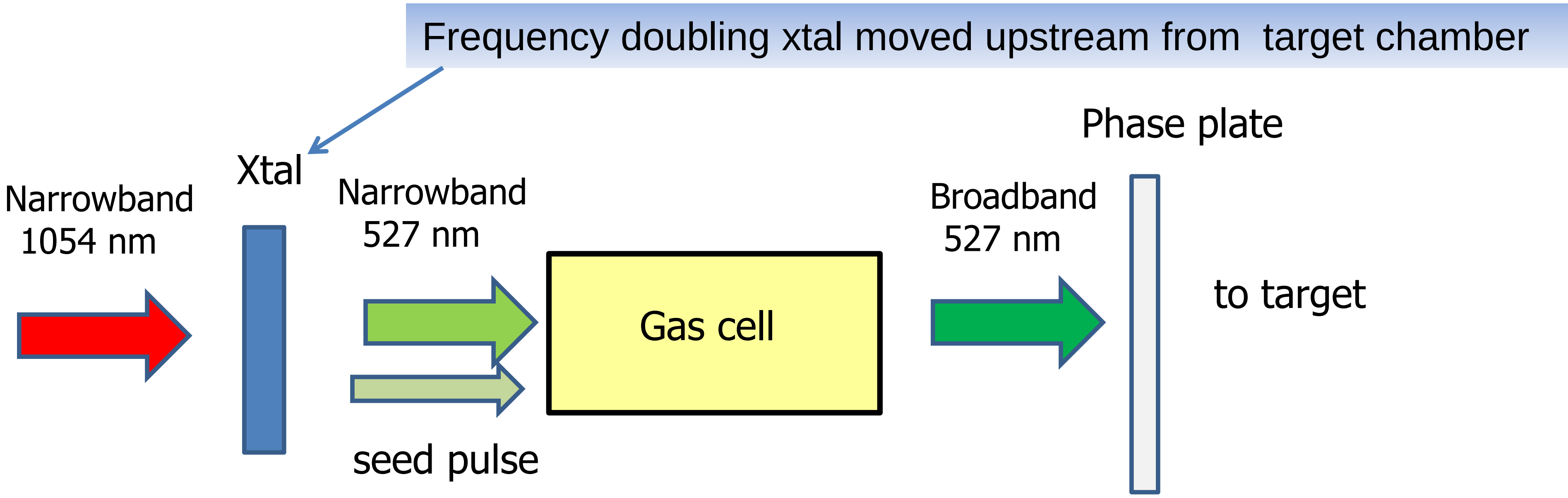


This prediction will be tested on Nike

SRRS may enable use of green light on NIF for indirect drive (more energy less LPI)



Green light ➔ potential for substantially more energy on target for indirect drive
Broad bandwidth ➔ suppression of LPI and CBET in gas filled hohlraums

- Detailed configurations for application to NIF are being examined in collaboration with David Eimerl, Eimex.
- Discussions underway for possible experiment on Omega Facility

Requirements for robust ignition and high yield with laser direct drive

- Highly symmetric implosions →
  - Highly uniform laser illumination & targets
- Minimize hydro instability →
  - Highly uniform laser illumination & targets
  - Hybrid approach with high-Z layers
  - Utilize low aspect ratio targets
- Minimize risk of LPI →
  - Deep UV laser light , broad laser bandwidth
- Mitigate CBET →
  - Laser focal zooming, broad laser bandwidth

KrF and ArF Excimer lasers are very attractive for this application

- Deep UV – 248 nm for KrF and 193 nm for ArF
- Easy to zoom
- Broad native bandwidth (> 1 THz)
- Gas laser media is easier to cool allowing higher shot rates

FASTRAD3D shows the expected increase in ablation pressure with decrease in laser wavelength

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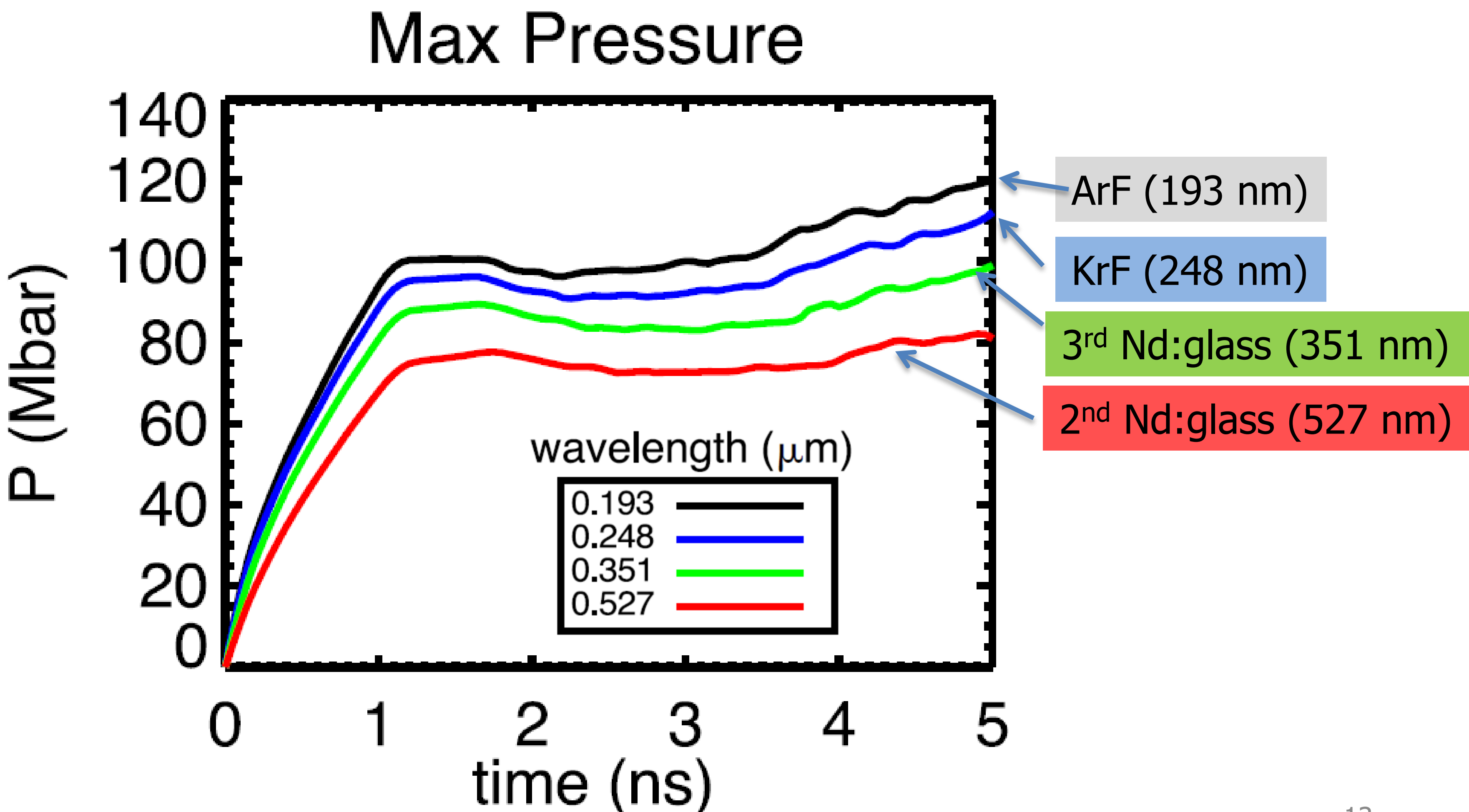
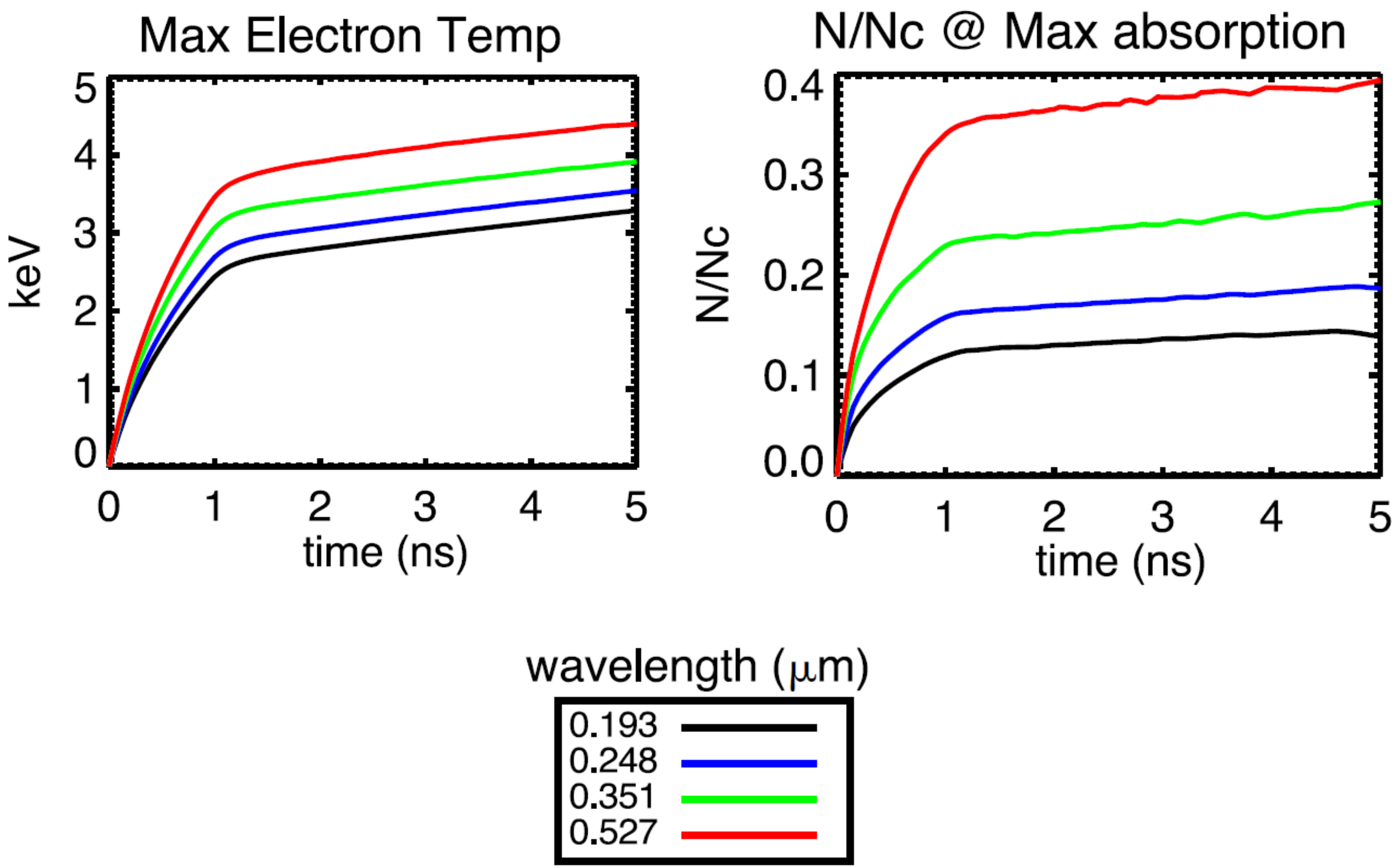
5 ns square wave laser pulse incident on 2.6 mm diameter plastic sphere @ 10^{15} W/cm^2 (vacuum intensity)



Coronal blow off temperature goes down and laser light is absorbed at lower faction of n_{cr} with deeper UV



Hydrocode simulations show advantages of utilizing short wavelength light towards avoiding two-plasmon decay LPI

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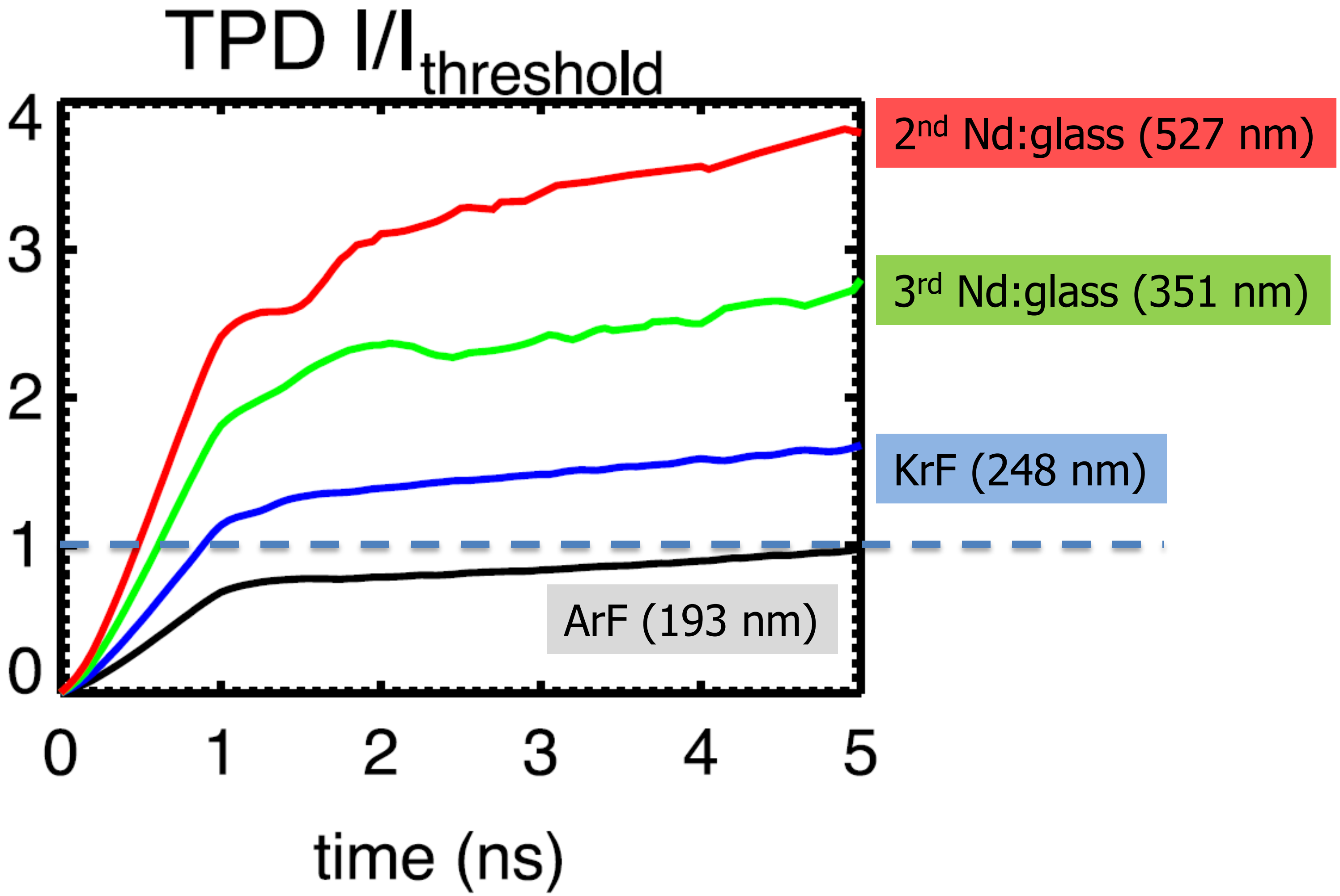

I_threshold [10^{15} W/cm^2] = 8.06 * Te[keV] * 1/(laser_wavelength[um]) * 1/Ln [um]
(Simon et al., Phys. Fluids 26, 3107 (1983).)

Summary

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- NRL participates in advancing ICF S&T with existing facilities.
- SRRS may enable broad enough bandwidth to suppress LPI on NIF.
- Excimer lasers have significant advantages in the target physics, and could be the laser of choice for future systems. (investment needed)