Development of MHz Frame Rate Optical Diagnostics for Hypersonic Ground Test Facilities

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NASA –ROA Program Review
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Outline

- Program Objectives and Burst Mode Laser Overview
- Major NRA Program Goals and Task Structure
- Progress To Date
- Future Work

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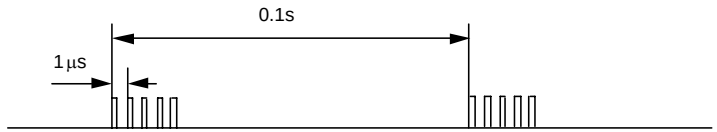
Stated Program Objectives

"To develop MHz-rate diagnostics for velocity, temperature, pressure, and species concentration based on technological improvements to a wavelength-tunable, narrowband, burst-mode laser system, and adaptation of several diagnostic techniques to burst mode operation."

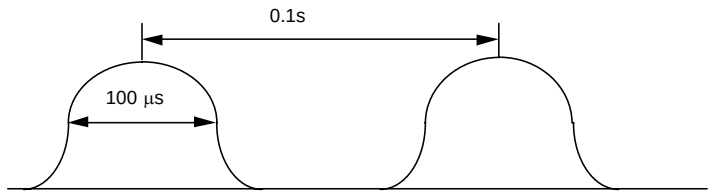
Pulse Burst Laser Concept

(Based on Lempert and Miles,et. al., AIAA-96-0500, 1996)

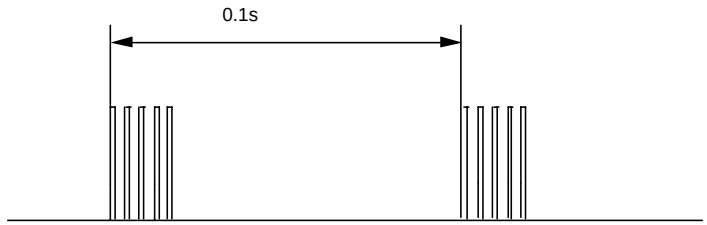
(a) CW laser is sliced into pulse-burst, repeated every 0.1s



(b) Nd:YAG gain curve



(c) Result is high power "burst" of 1~~99 pulses



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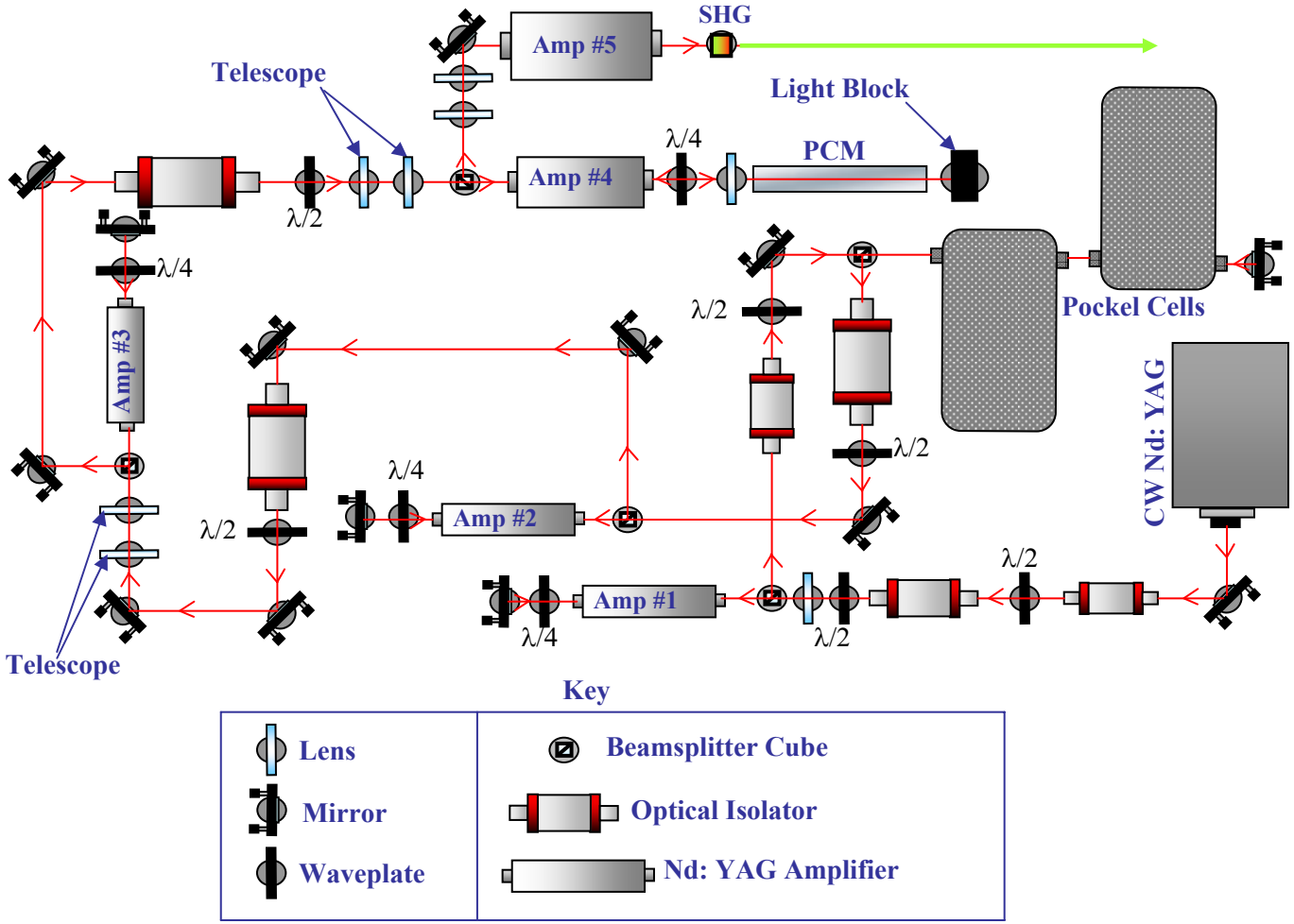
Pulse Burst Laser System



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MHz Frame Rate Camera

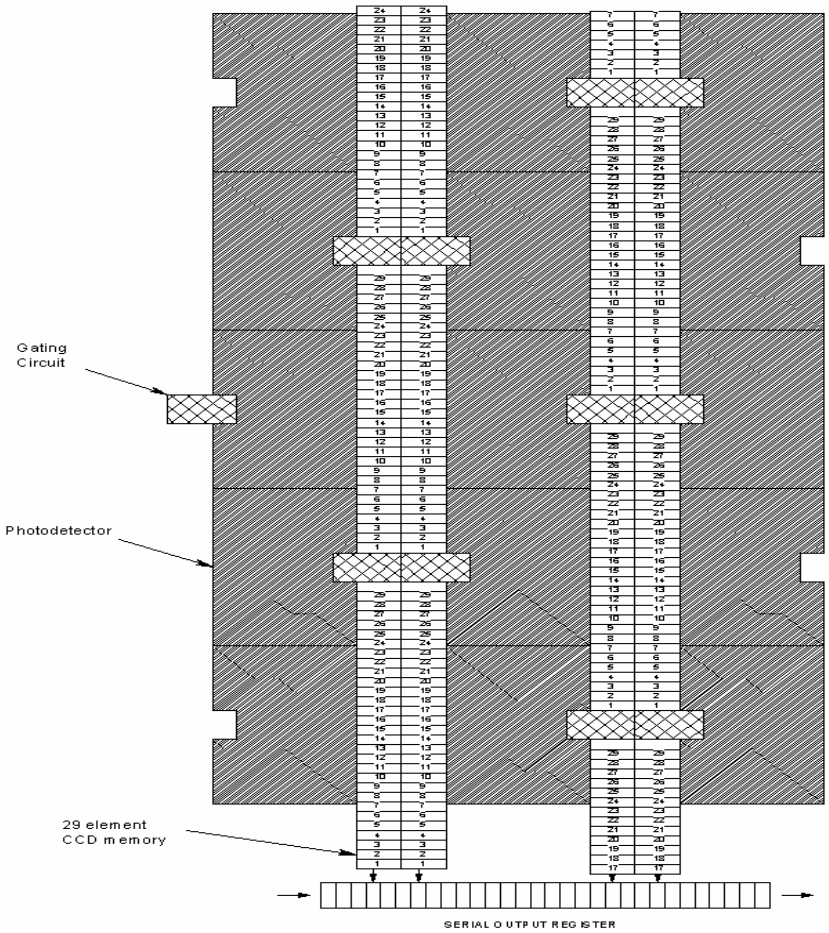
Princeton Scientific Instruments Camera (PSI-IV)

28 frames (80 x 160 resolution per chip) at up to 1 MHz

(Up to four chips per camera)

Custom CCD chip incorporates image memory on each pixel.

Intensified version recently developed and is available for this project.



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Why Operate In "Burst" Mode

Three Basic Modes of Burst Mode Operation

- **Temporally Resolve Unsteady Flow Behavior in "Long" Run Time Facilities**

  ("Single Shot" Measurements at ~ 100 kHz Frame Rate)

- **Spectrally Resolved PLIF**

  ("Averaged" T, P, vel, species data over ~20-50 kHz rate)

- **20-50 Image Acquisition in Single Run of "Impulse" Facility**

All Three Capabilities Are Being Addressed In This ROA Project!

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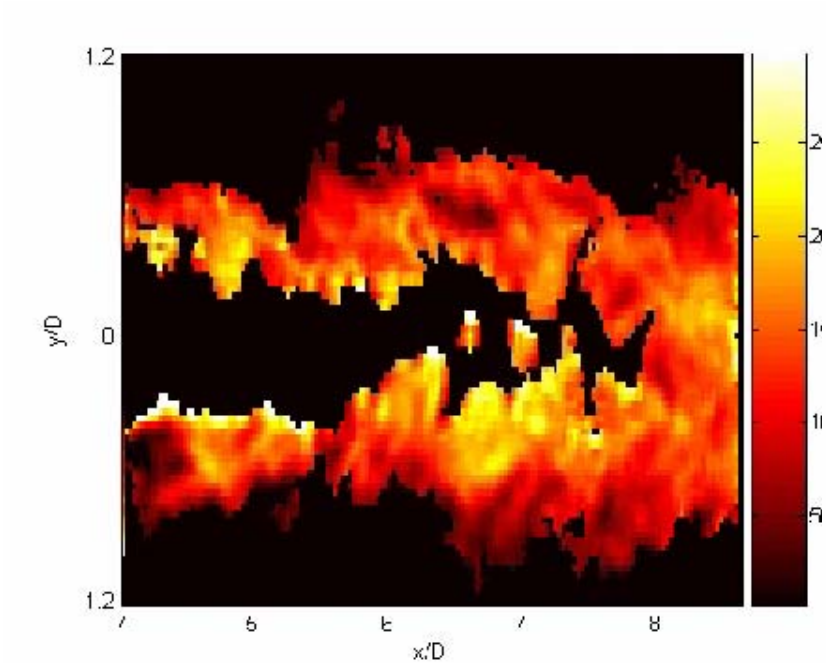
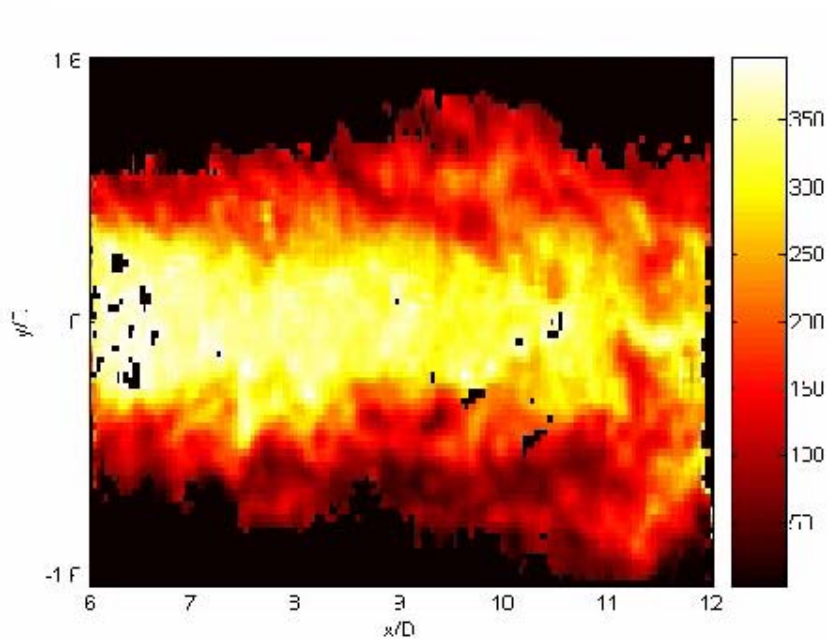
Example – Velocity Field Measurements in Mach 1.3 and 2.0 Axisymmetric Jets Using PDV – 250 KHz Frame Rate

Mach 1.3 Jet
Unseeded Core



Mach 2.0 Jet
Seeded Core



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ROA – Basic Task Structure

- **Task I - Burst Mode Laser Enhancement.**
  - i. Envelope Extension.
  - ii. Pulsed Oscillator
  - iii. Rapid Wavelength Scanning
- **Task II - Burst Mode Diagnostic Development.**
  - i. NO MTV
  - ii. Rapid Scan PLIF Imaging (T, P, vel, species)
- **Task III – Demonstration and Technology Transfer**

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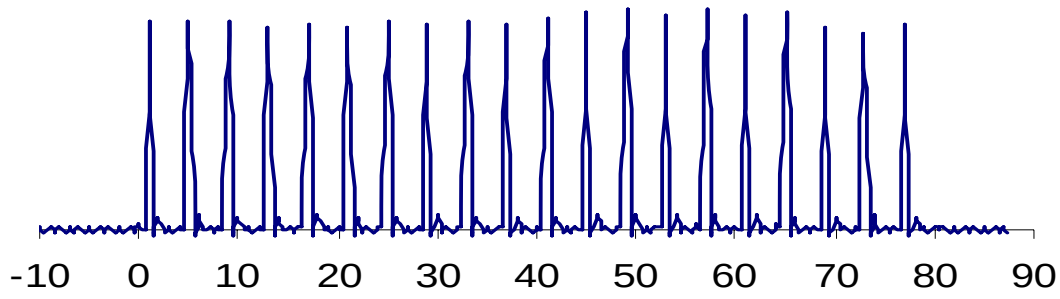
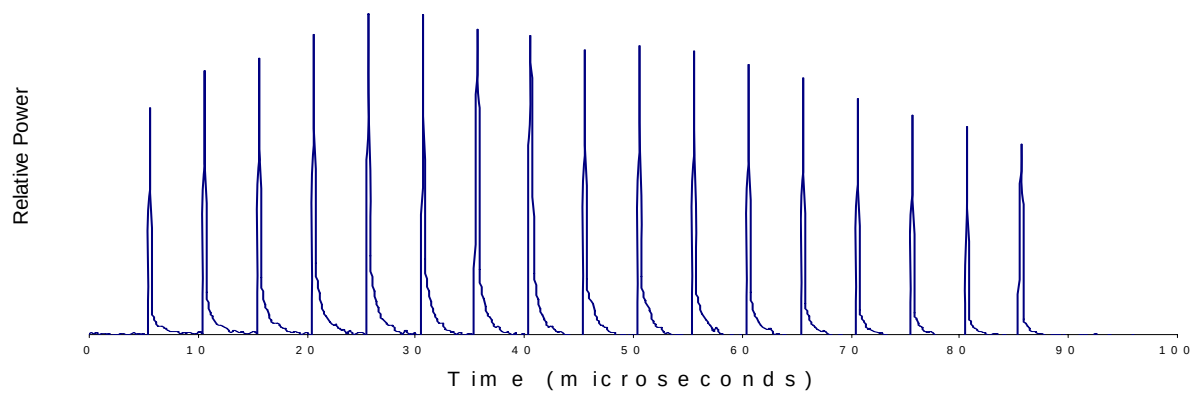
Typical 532 nm Burst Sequences at Low Energy
Original Fixed (300 microsecond) Length Power Supplies

20 pulses, 4us spacing, 2.5mJ/pulse



17 pulses, 5 µs spacing, 7 mJ/pulse



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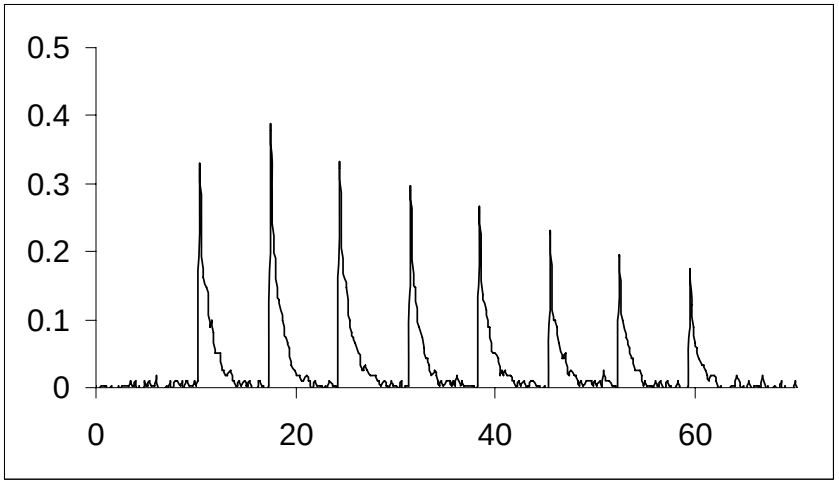
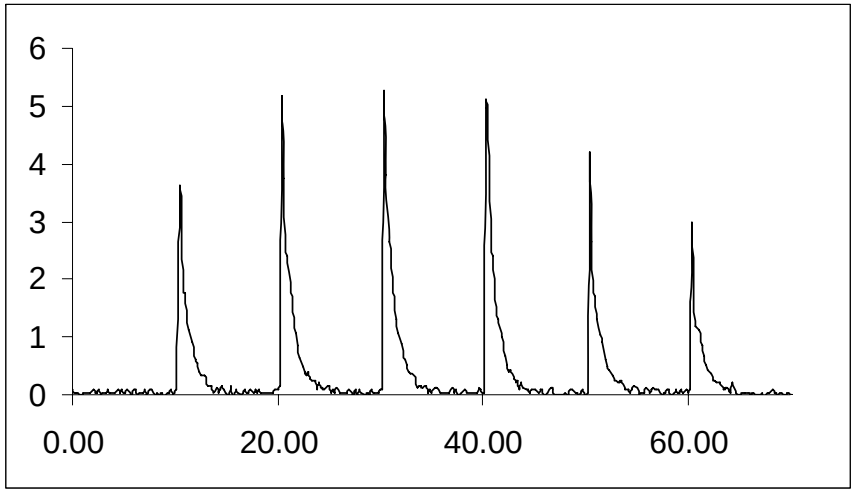
Typical 532 nm Pulse Sequences - Higher Power

Original Fixed (300 microsecond) Length Power Supplies



8 Pulses
60 mJ per Pulse
8 usec spacing



6 Pulses
80 mJ per Pulse
10 usec spacing

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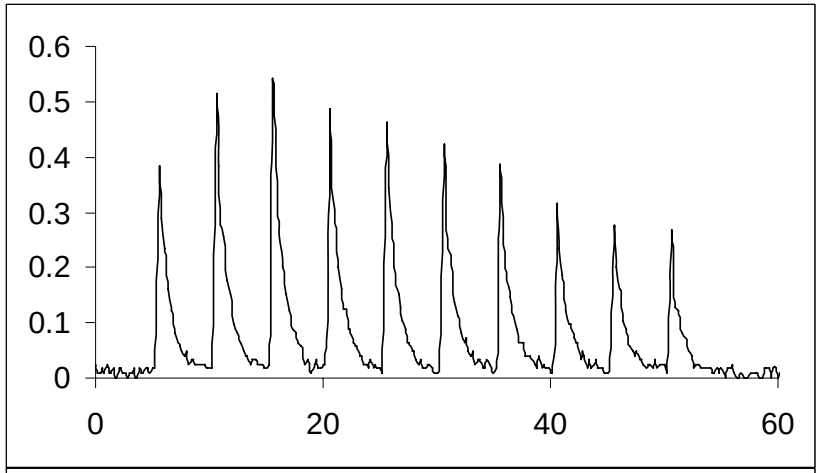
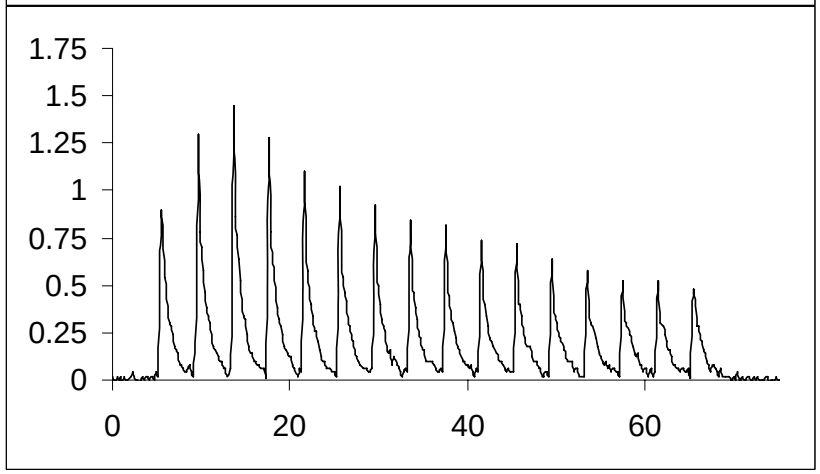
Typical 532 nm Pulse Sequences - Higher Power

Original Fixed (300 microsecond) Length Power Supplies



10 Pulses
54 mJ per Pulse
5 usec spacing



16 Pulses
18 mJ per Pulse
4 usec spacing

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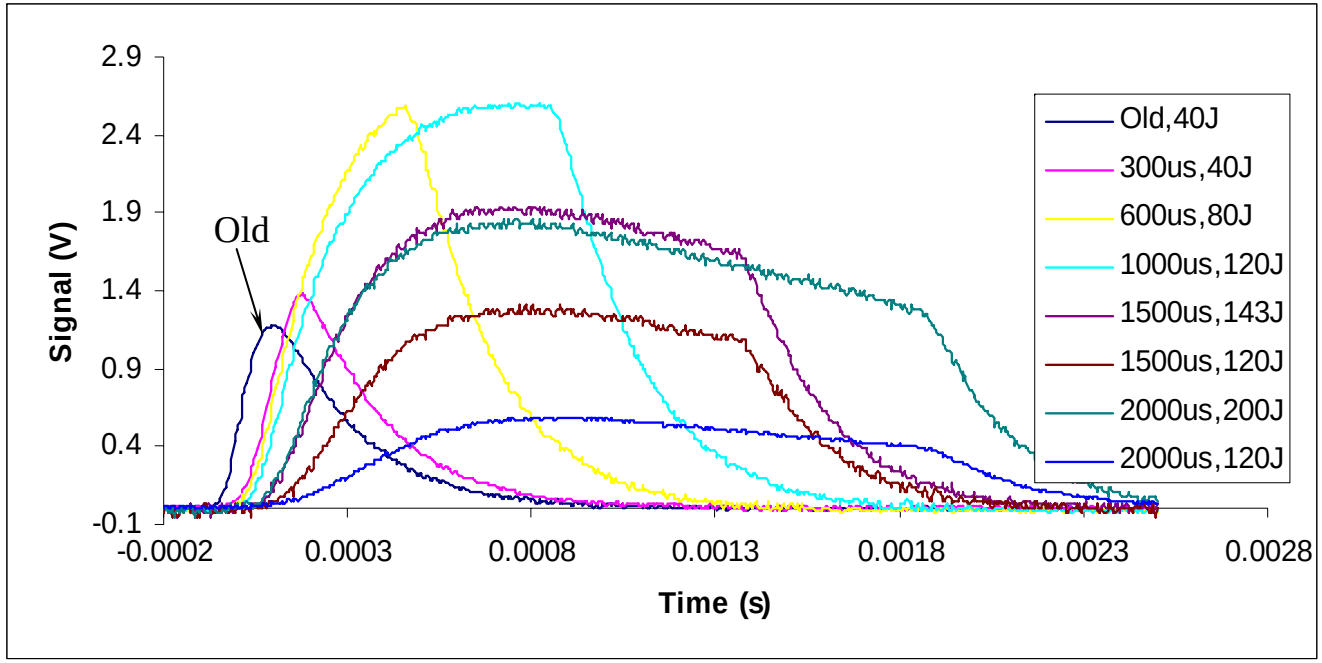
ROA Year I Goal – Envelope Enhancement

Comparison between "traditional" 300 us and variable "flat pulse" power supplies.



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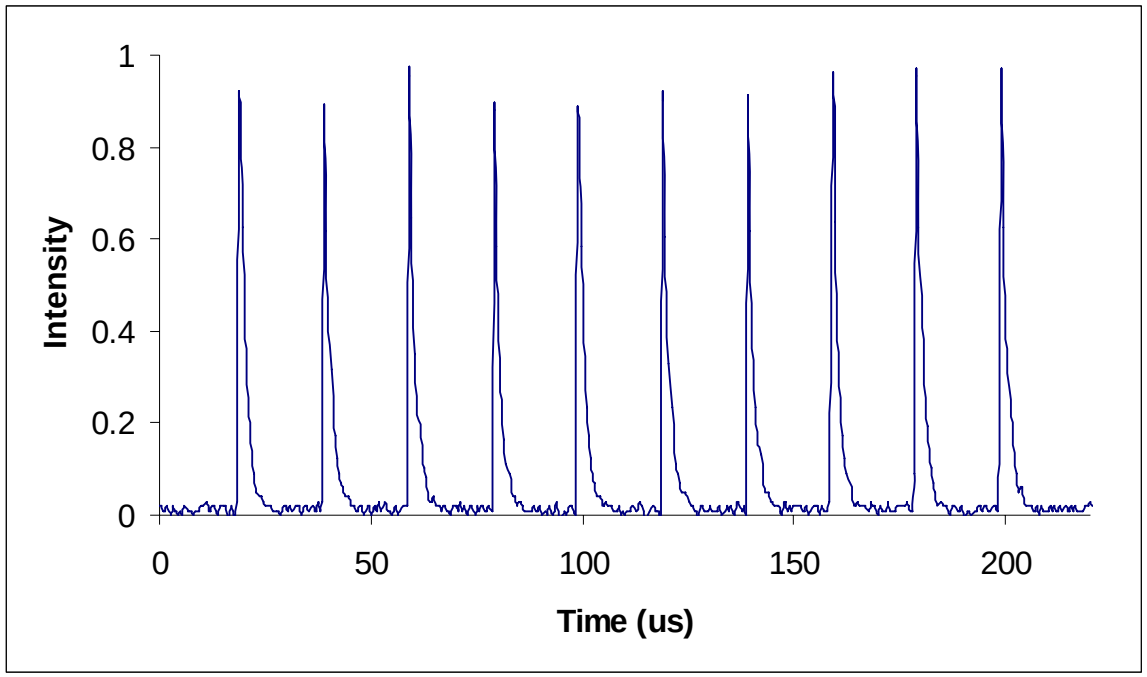
NRA Year 1 Results – 1064 nm Envelope Extension

(Using New Power Supplies Procured Under This Project*)

10 pulses – 20 µsec spacing – 240 mJ/pulse



(*Arrived August, 2007)

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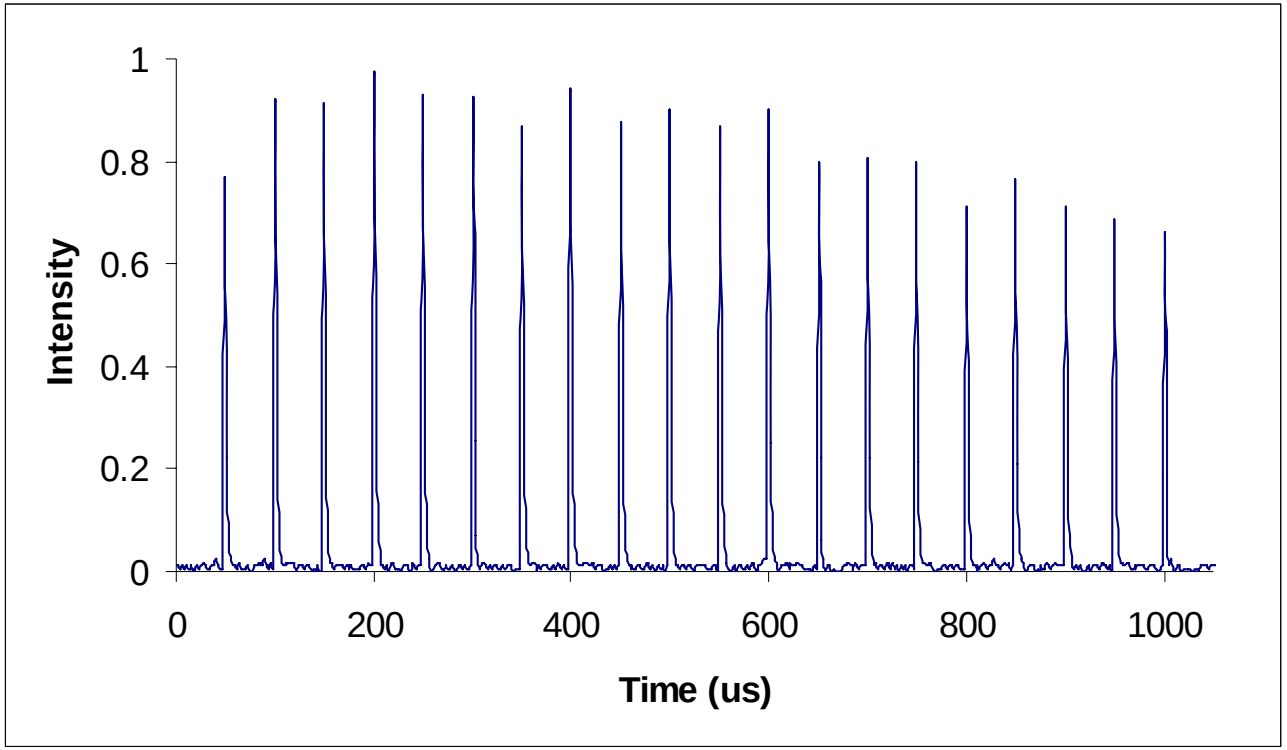
NRA Year 1 Results – 1064 nm Envelope Extension

20 pulses – 50 us spacing – 400 mJ/pulse



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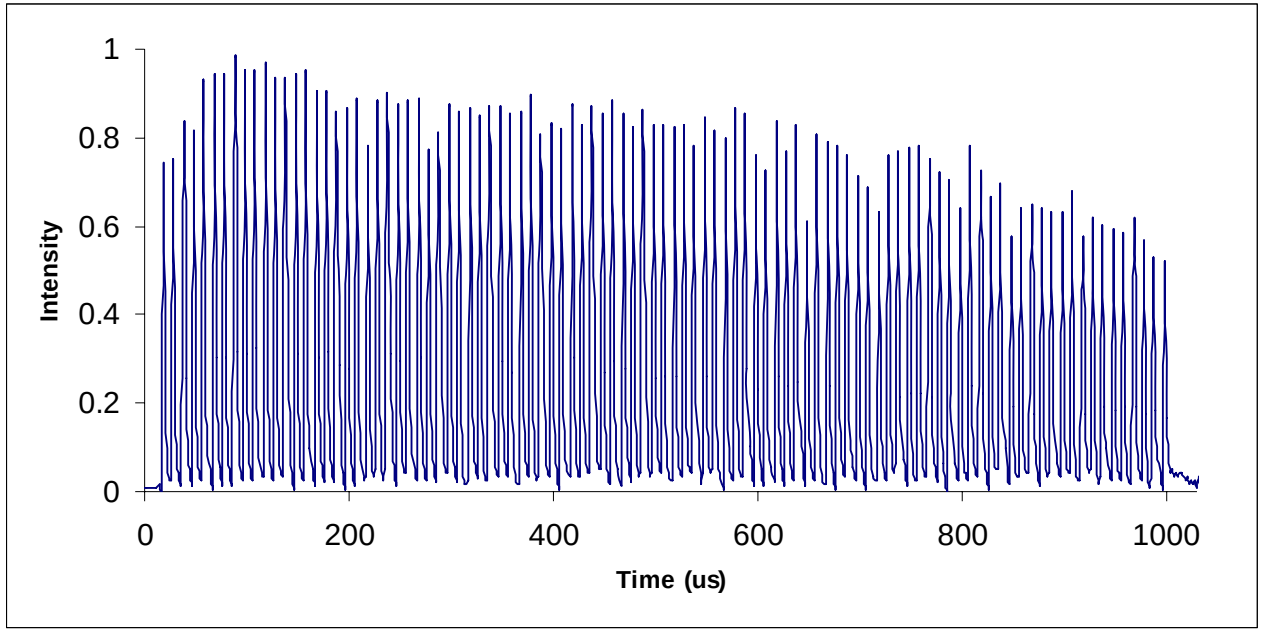
NRA Year 1 Results – 1064 nm Envelope Extension

100 pulses – 10 us spacing – 27 mJ/pulse

(This is sufficient for "Mie" Scattering-based Imaging)



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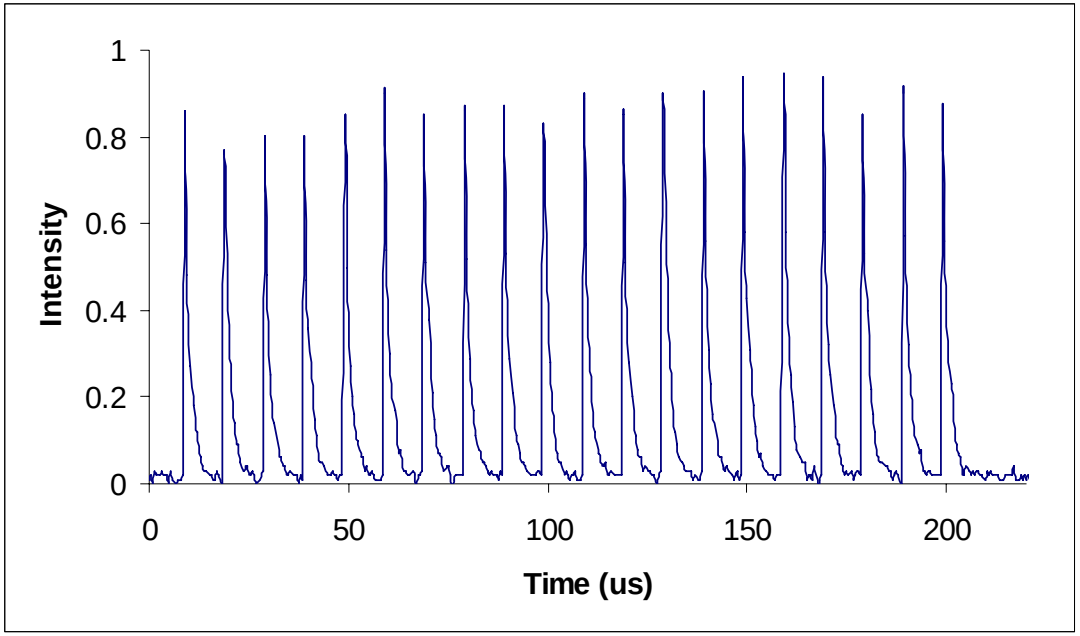
NRA Year 1 Results – 1064 nm Envelope Extension

20 pulses – 10 us spacing – 87 mJ/pulse

(We should be able to increase the energy/pulse by factor of two - three)



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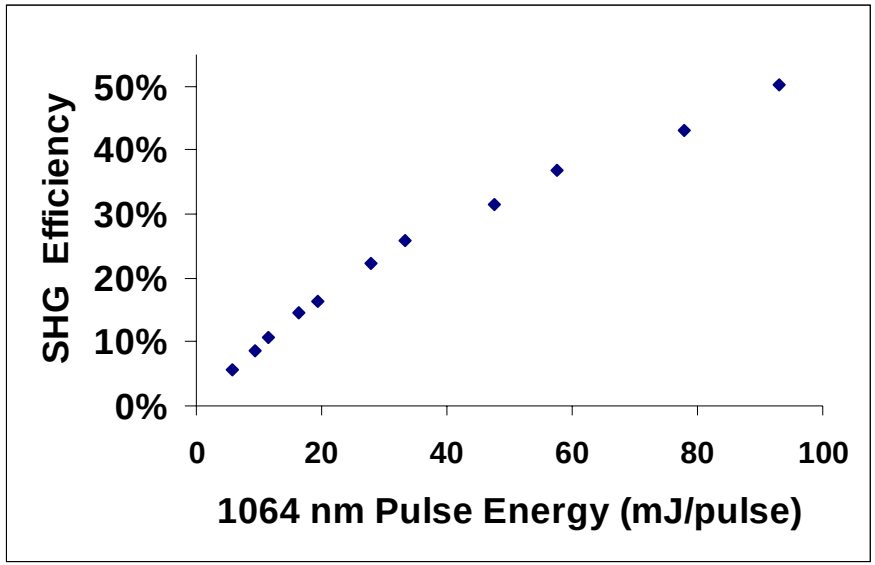
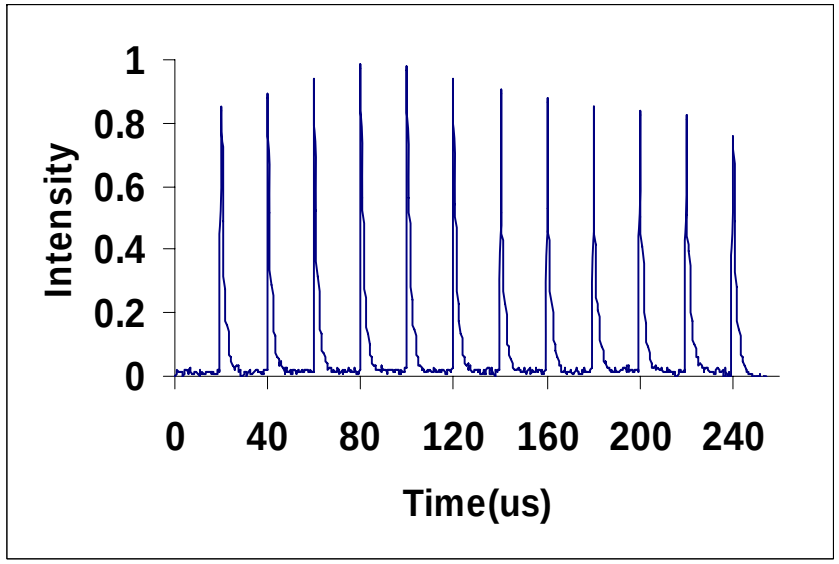
NRA Year 1 Results – 532 nm

(We are being conservative with energy input to SHG crystal)

2nd Harmonic Conversion Efficiency
Type II KTP - 12 pulse burst



Typical 532 nm burst
~95/48 mJ/Pulse @ 1064/532 nm



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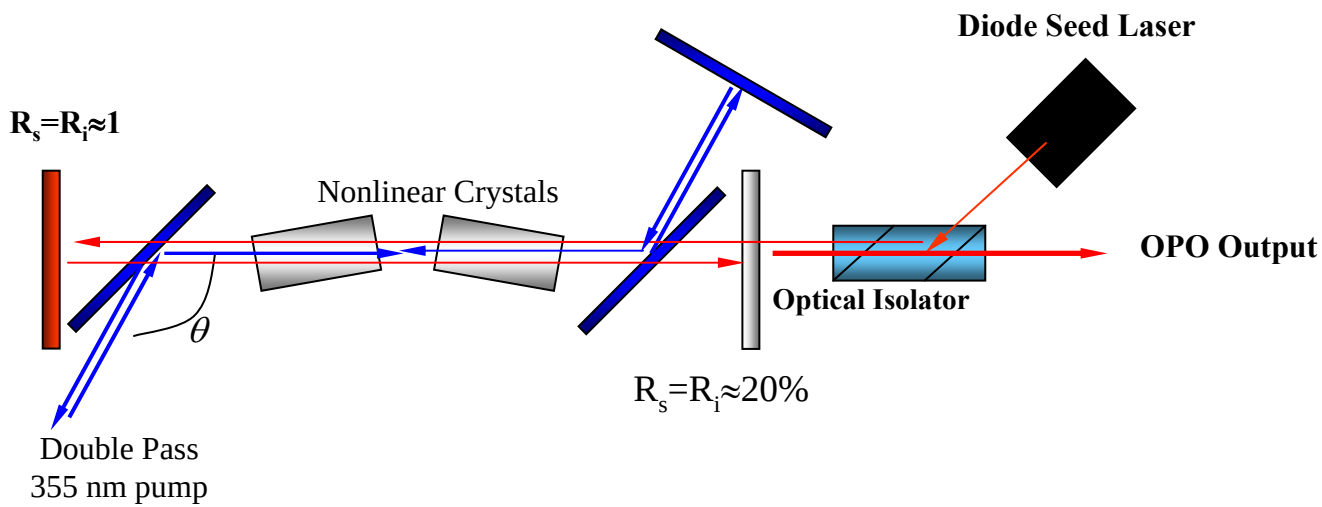
Injection-Seeded OPO For Burst Mode Tunable Output
(For Burst Mode PLIF Imaging)



Note: Seeding at Idler Wavelength

$$\frac{n(\lambda)}{\lambda_3}=\frac{n(\lambda)}{\lambda_1}+\frac{n(\lambda)}{\lambda_2}$$

λ_1 = 622 nm
λ_2 = 827 nm
λ_3 = 355 nm

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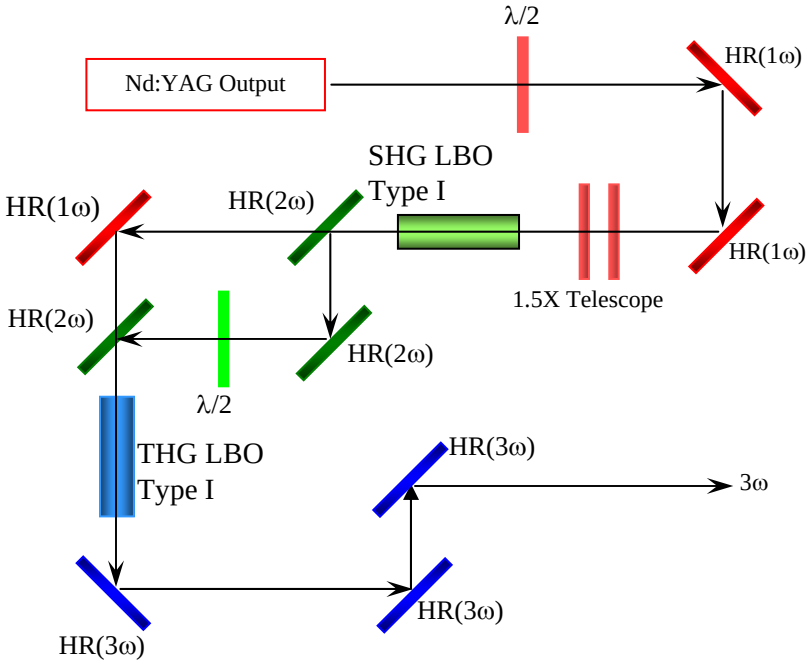
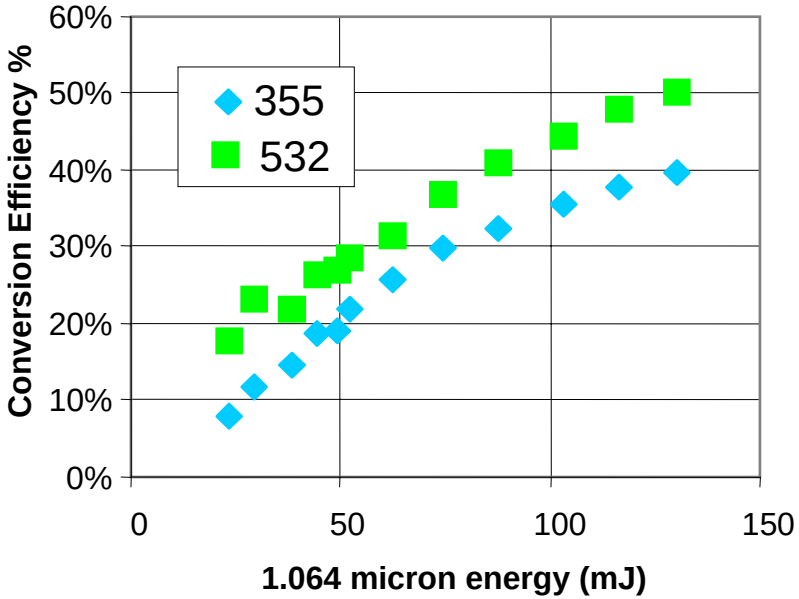
Third Harmonic Generation

Schematic of Type I "Non-Critical" Phase Matched THG



Efficiency (Averaged over 6 pulse burst – 5 usec spacing)



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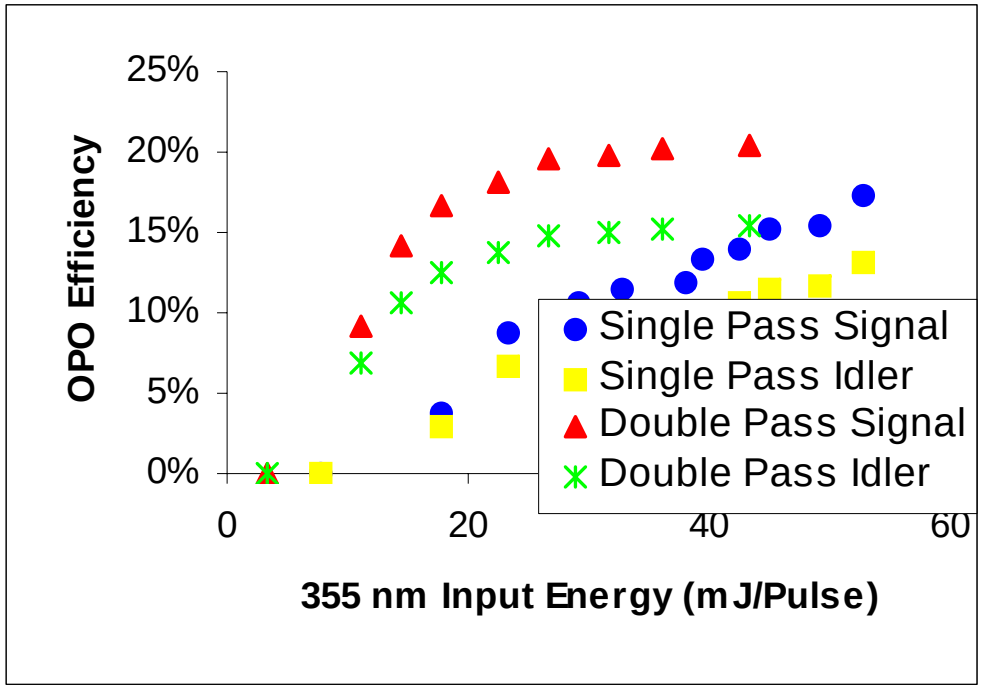
OPO Conversion

Signal/Idler Power Conversion
(photon conversions are identical)

$\lambda_{sig} = 622$ nm

$\lambda_{idler} = 827$ nm



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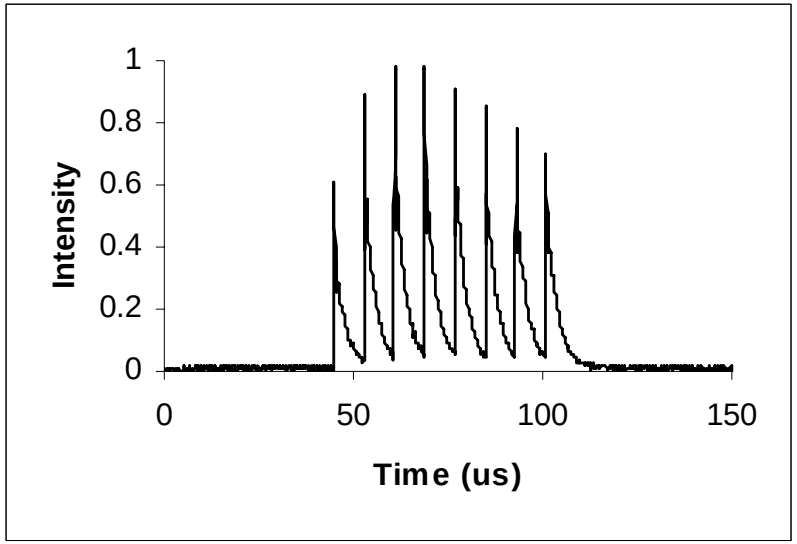
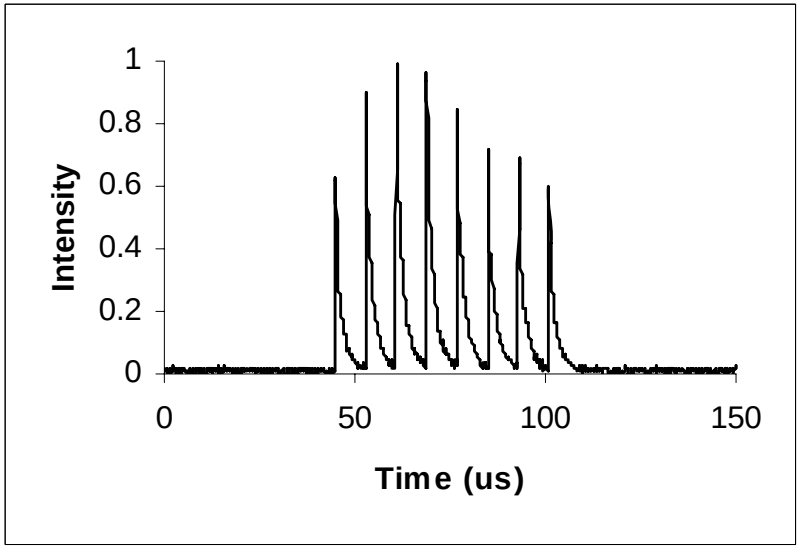
Burst Mode OPO Output (Old Power Supplies)

8 Pulses – 8 microsecond spacing

355 Pump Sequence
Average Pulse Energy: 26 mJ



OPO Output Sequence
Average Signal/Idler Pulse Energy: 3.7/4.9 mJ



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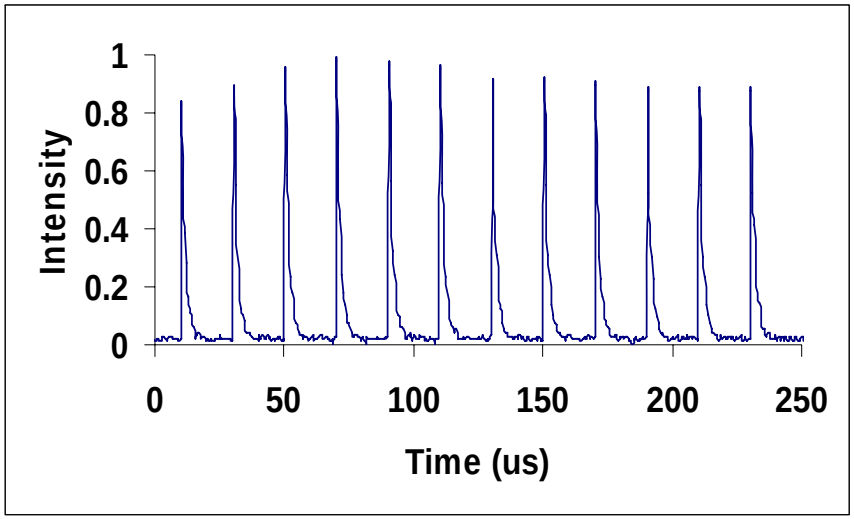
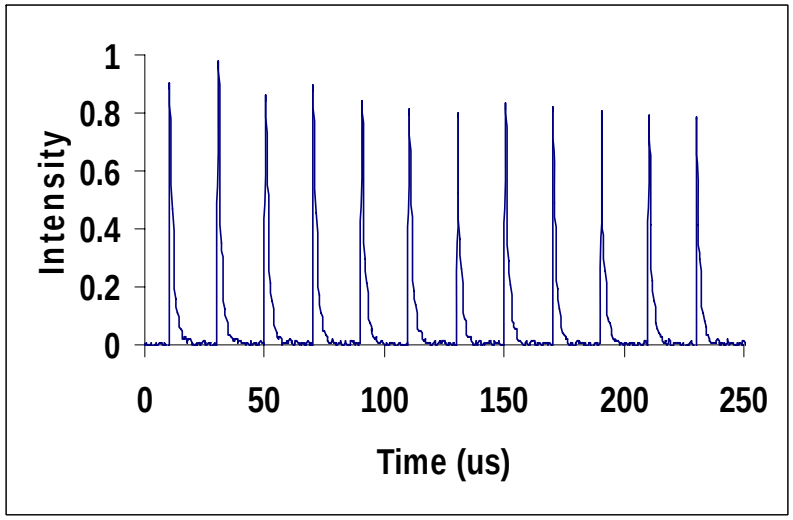
NRA Year 1 Results: OPO Bursts With New Power Supplies

355 nm Burst – 25 mJ/pulse
(~20% Conversion from 1064*)



452 nm Signal – 2.5 mJ/pulse



(Old THG Crystal Has Degraded – New One Ordered Late August, 2007)

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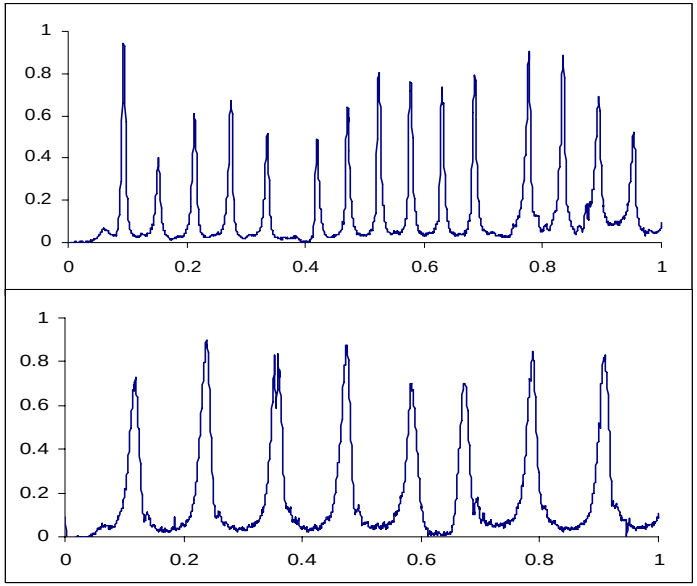
NRA Year 1 Results: Injection Seeded OPO Linewidth

(Determined with Borrowed Dual Fizeau Wavementer)

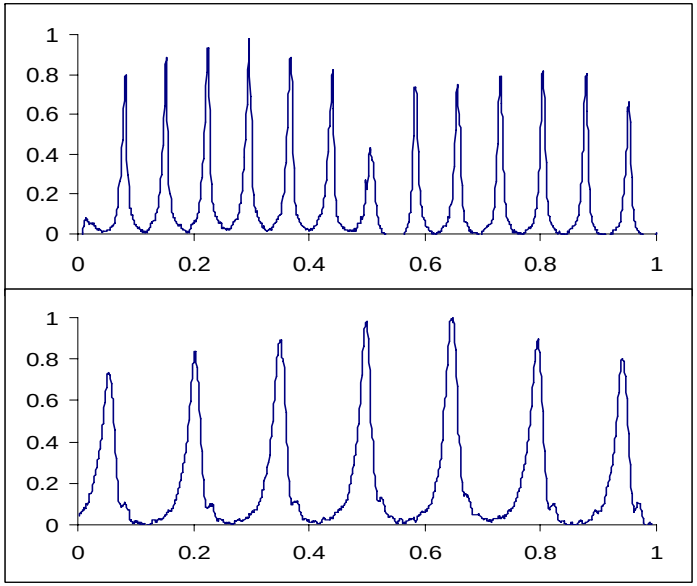
$\Delta\upsilon_{FWHM}$ ~300 MHz for Both Signal and Idler

($\Delta\upsilon_{FWHM}$ ~400 MHz (355 nm OPO Pump - ESTIMATED)

827 Idler Fringes



622 Signal Fringes



Linewidth is ~FT limit without any cavity stabilization!

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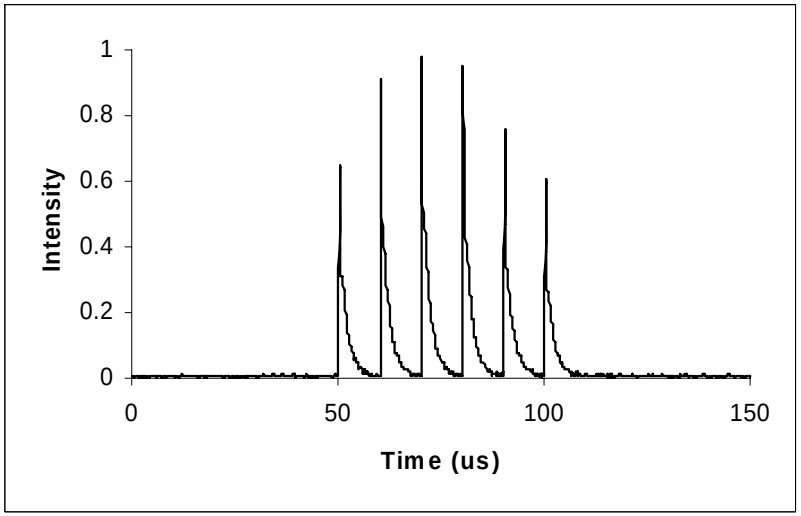
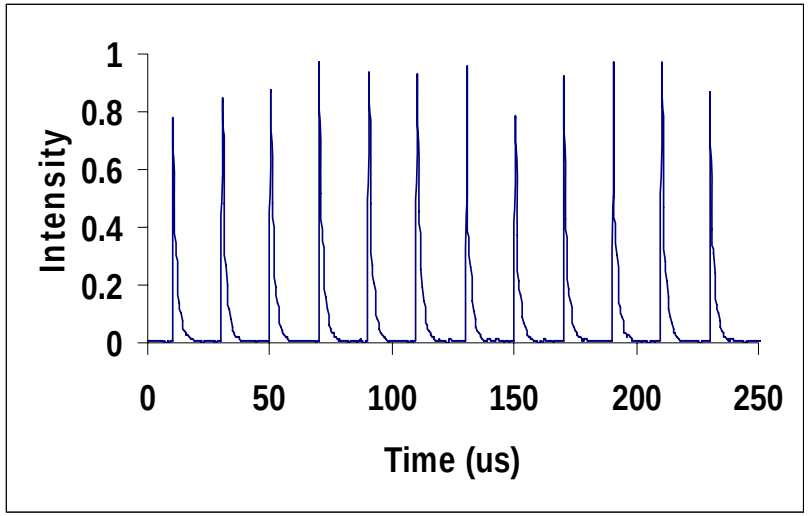
NRA Year 1 Results: Comparison of Old and New Power Supply For Generation of 226 nm (For NO PLIF)

Old Supplies



New Supplies



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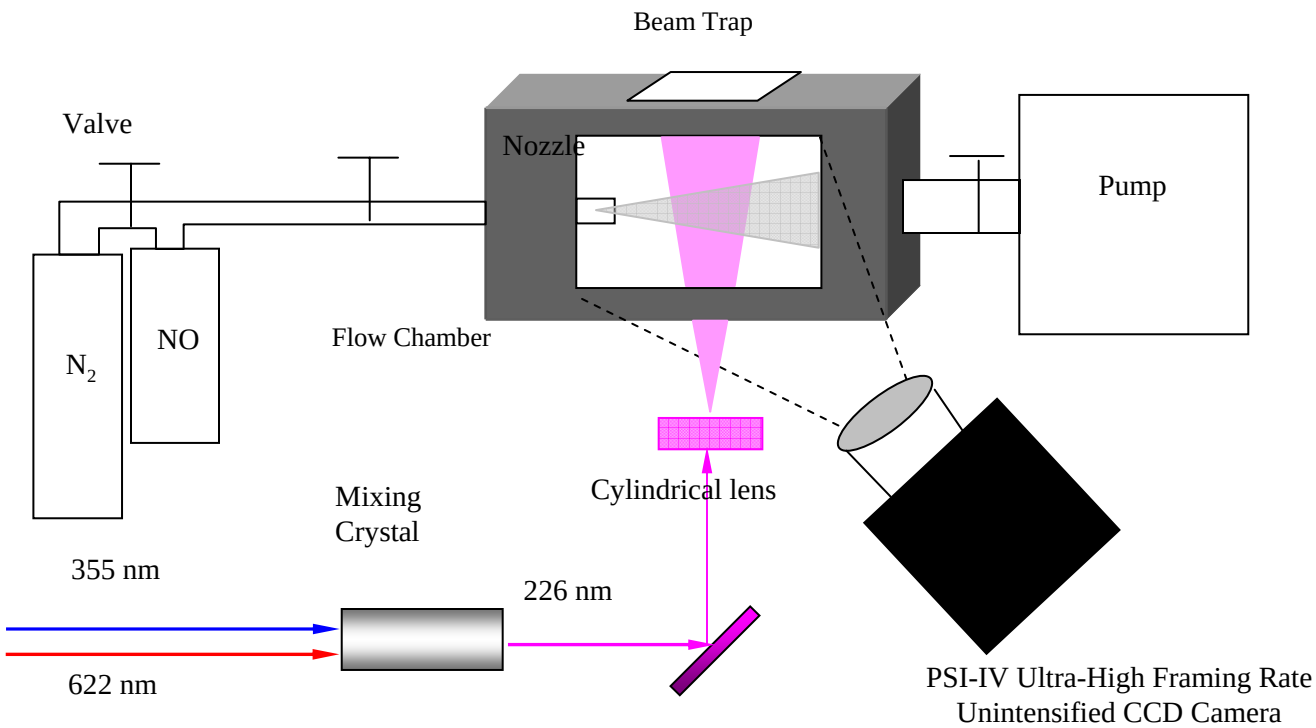
Preliminary NO PLIF Imaging

Mach 2 Micro Jet:1×5 mm; ~3% NO seeded into N_2



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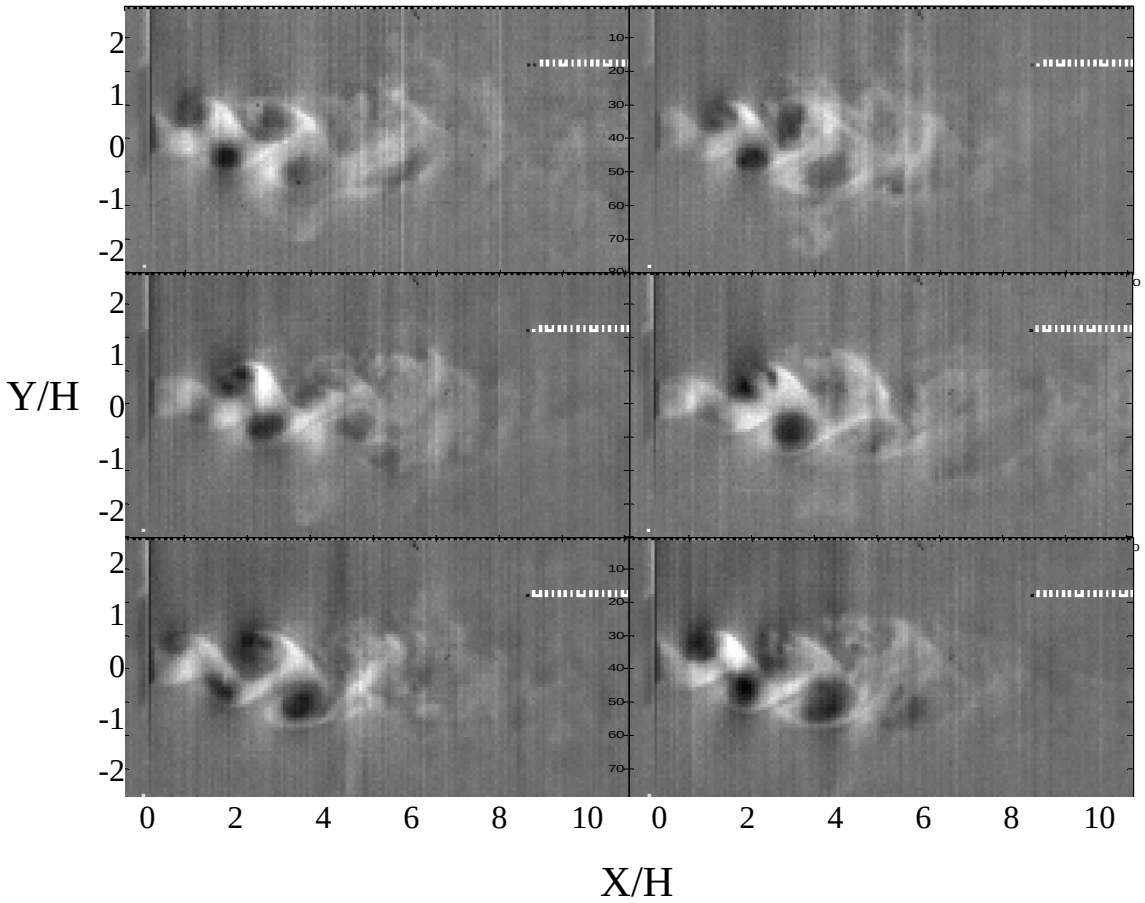
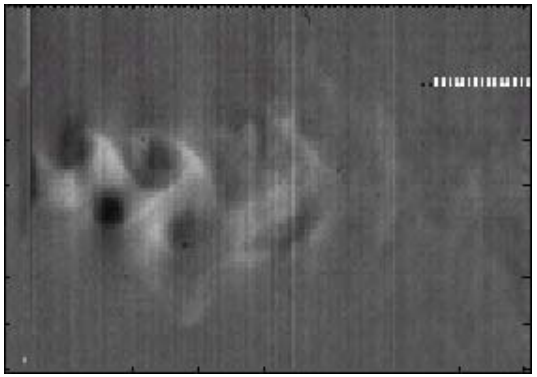
Burst Mode NO PLIF Imaging Preliminary Result

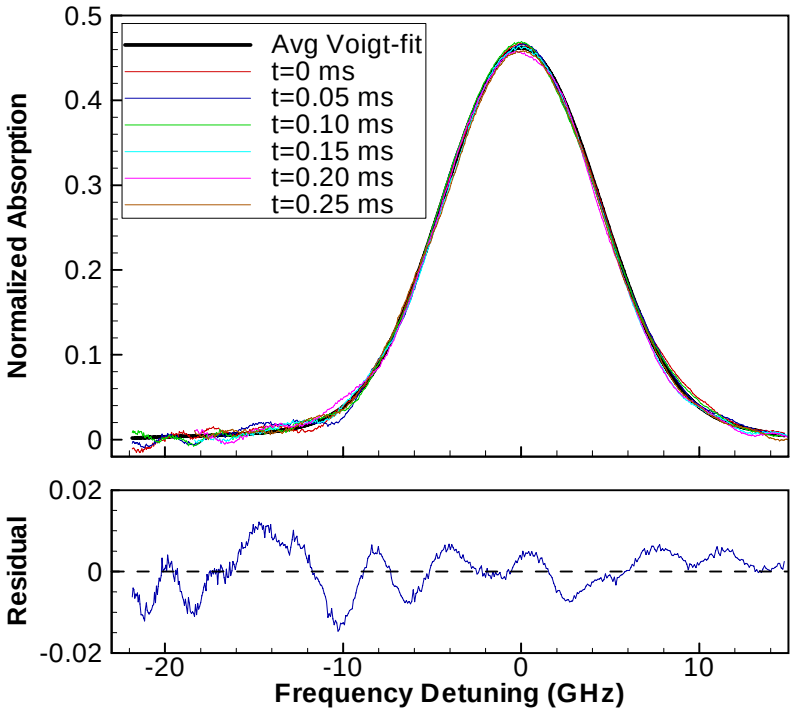


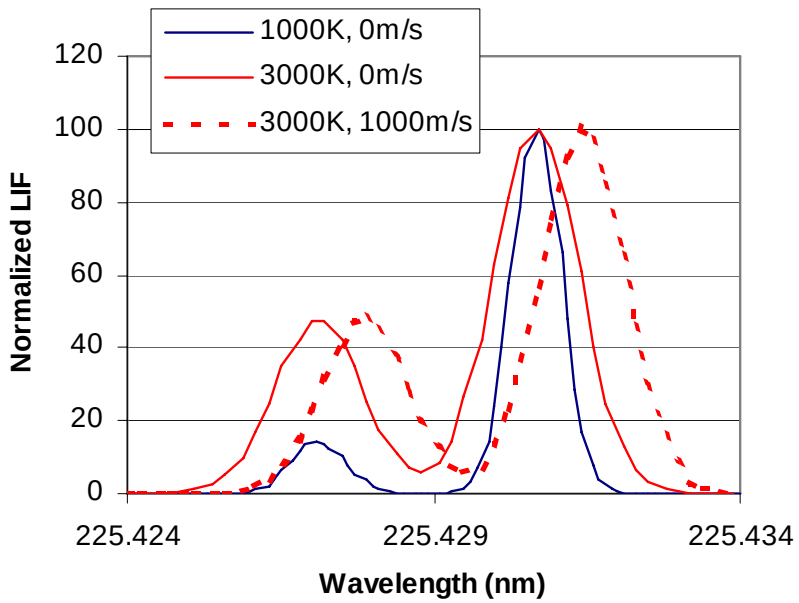


P_s/P_a=248/95 torr, Overexpanded

ROA Near Term Future Work (First Experiments Planned for December, 2007) Rapid Wavelength Tuning*

Replace ECDL Seed Laser With Rapid (~50 kHz) Scan DFB Diode Laser





*Terry Meyer, ISU

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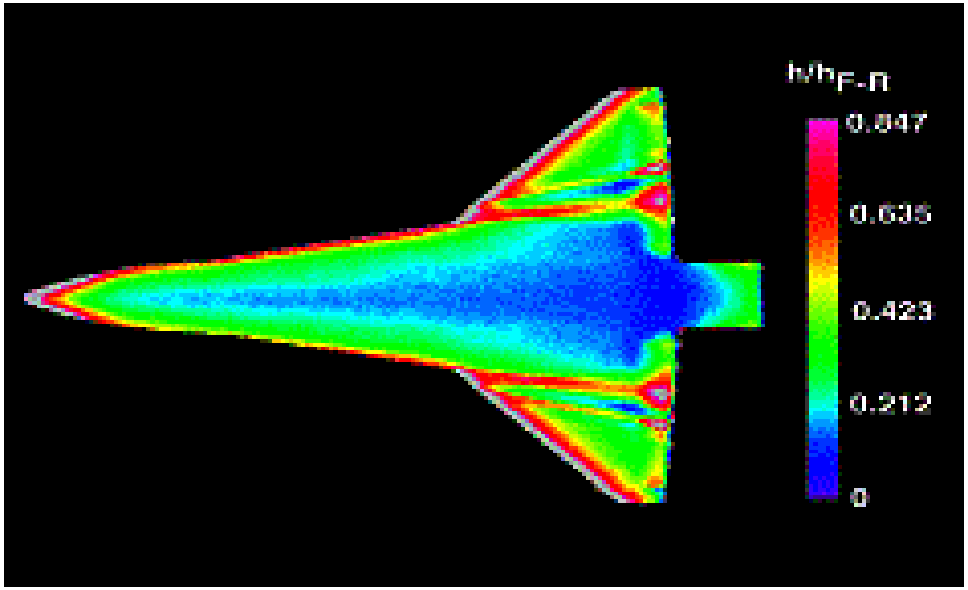
ROA Future Work

Perform NO PLIF Measurements in NASA-Langley 31” Mach 10 Facility (Facility Targeted At Year 1 Kick-off Meeting)



Surface Heating Image of X-34 Acquired with Thermographic Phosphor Technique

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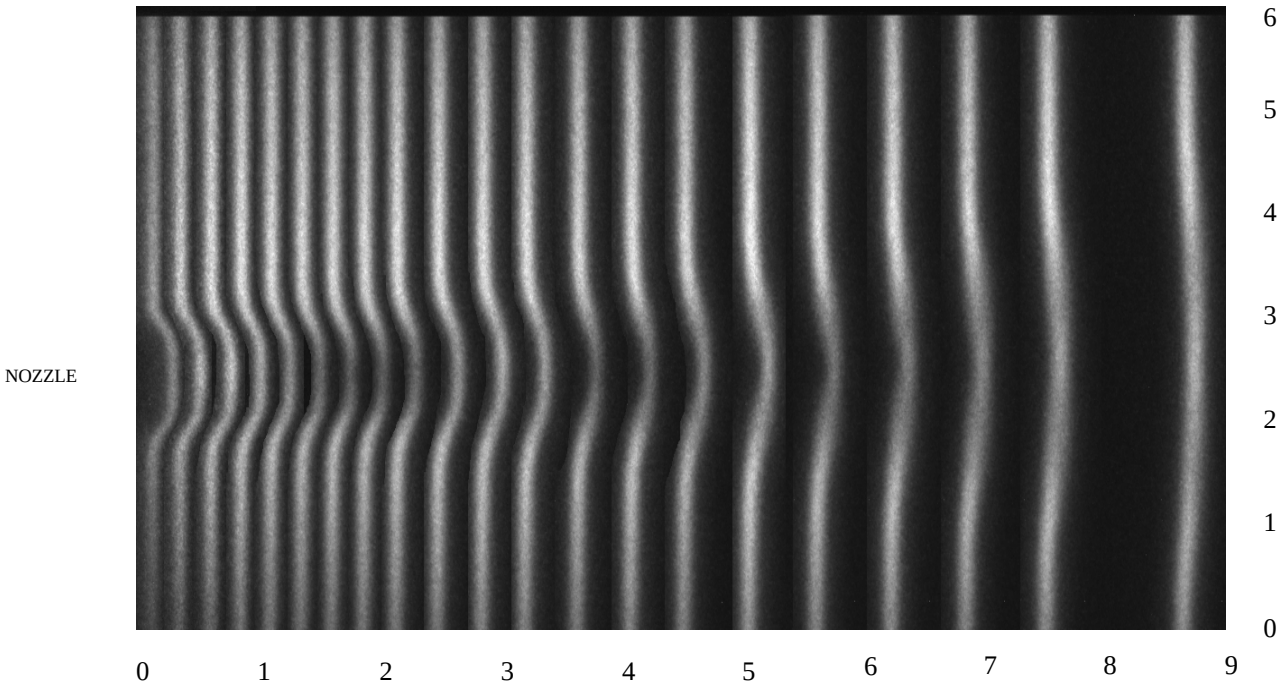
Future Work (Year 2) – NO MTV

Collage of 50 laser shot averaged acetone MTV images of flow produced by pressure matched, Mach 2 nozzle. Static pressure is ~ 10 torr.



Progress Summary (Based on NASA ROA Cooperative Agreement)

Year I

- Temporal Envelope Extension (Achieved: August-Oct, 2007).
- Increase 226 nm Energy to ~ mJ/pulse (Awaiting New THG Crystal.)
- Develop Rapid Wavelength Tuning (First Expts Planned Dec, 2007).

Year II

- Procure and Implement Pulsed Oscillator.
- NO MTV Demonstration in Lab Scale Supersonic Wind Tunnel.
- Rapid Wavelength Scanning Temperature PLIF

Year III

- Rapid Wavelength Scanning T, Velocity, Species PLIF
- NO MTV Grid Writing Demonstration
- Demonstration Measurement in Selected NASA Facility
  (Langley 31" Mach 10: Targeted at Kick-Off Meeting)

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Questions and Discussion??

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