# The Mercury Laser - Technical Progress Update

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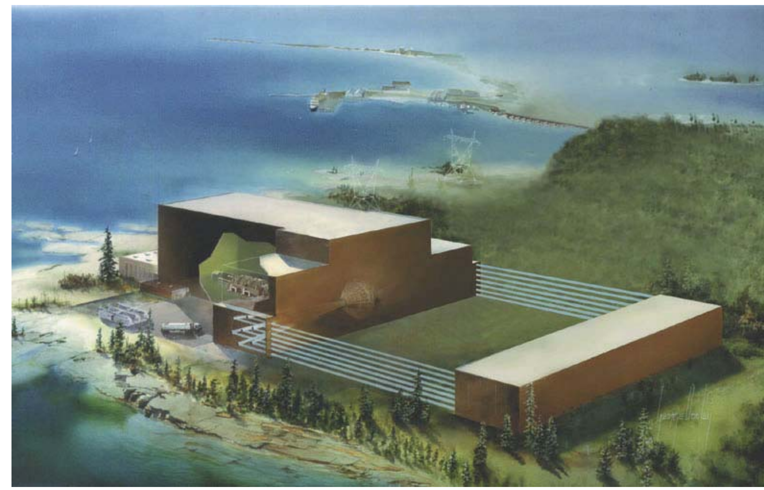
# Outline

- Project Overview
  - Mercury Laser performance goals
  - International 100 J class systems
- Laser architecture
  - Design
- System performance
  - Pump diode arrays
  - Crystalline gain media
  - Gas cooled amplifiers
  - Laser operations
- Upcoming activities
  - Frequency conversion
  - Front end (Andy Bayramian: Poster)
  - Next generation design considerations (Ray Beach: Poster)

# Mercury laser requirements are a melding of both NIF and IFE systems but at sub-scales

- **Energy:** 1.8 MJ
- **Pulse shape:** 3 ns shaped
- **Bandwidth:** 90 GHz; 1ω
- **Wavelength:** 0.35 μm

- **Efficiency:** 10%
- **Reliability:** >10$^9$ shots
- **Cost:** $500/J for laser, $0.05/W for diodes
- **Repetition rate:** 5-10 Hz



***Mercury Laser incorporates:***

***Diodes, crystals, and gas cooling***

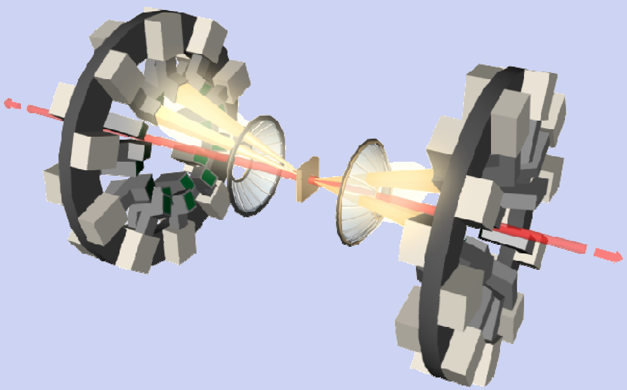
- **Energy:** 100 J
- **Pulse shape:** 3 -10 ns
- **Bandwidth:** 150 GHz; 1ω
- **Wavelength:** 0.5-0.35 μm
- **Efficiency:** 10 % (w/o utilities)
- **Reliability:** >10$^8$ diode shots
- **Cost:** $5/W for diodes
- **Repetition rate:** 10 Hz

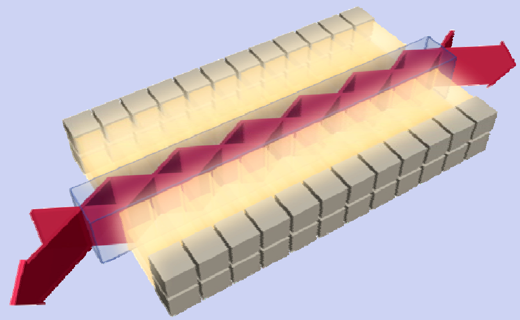
# Many different architectural approaches are being considered for rep-rated 100J systems

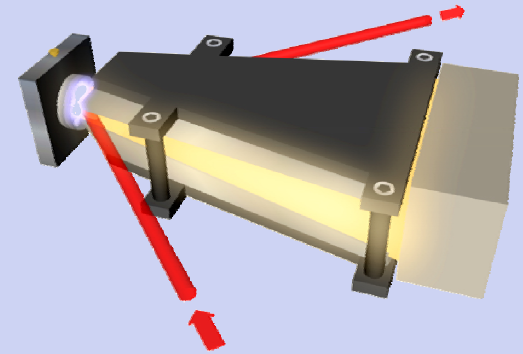
**Polaris - Germany**
Dr. Joachim Hein
Water cooled, longitudinal pumped
Yb:Flurophosphate disk

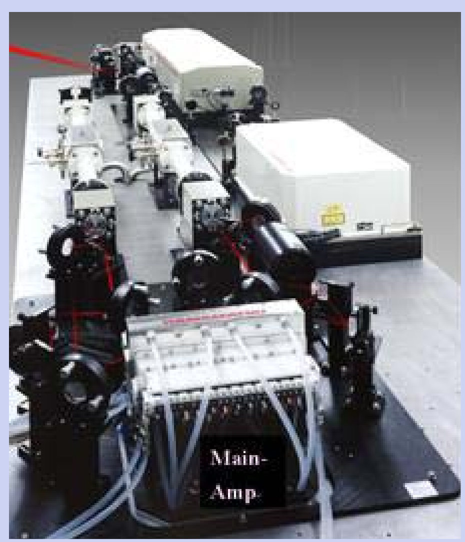
**HALNA - Japan**
Dr. Yasukazu Izawa
Water cooled, side pumped
Nd:Phosphate slab

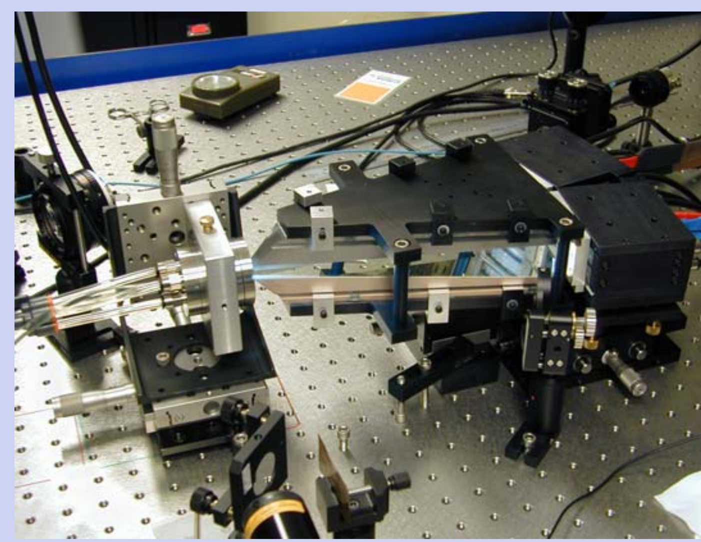
**Lucia - France**
Dr. Jean-Christophe Chanteloup
Water cooled, longitudinal pumped
Yb:YAG disk









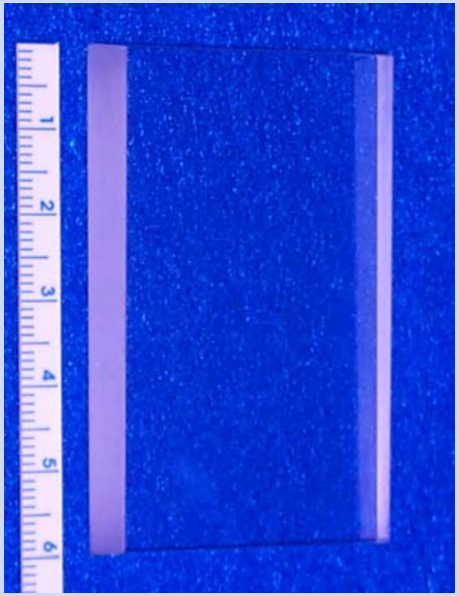



# Summary table of performance goals for high energy 1 μm DPSSL efforts around the world

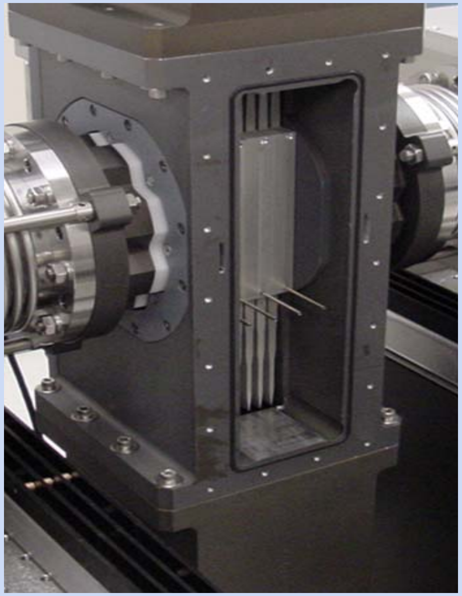
| Project | Polaris<br>Germany | HALNA<br>Japan | Lucia<br>France | Mercury<br>United States |
|---|---|---|---|---|
| Application | High energy radiation source | IFE | Laser matter interaction | IFE |
| Gain Media | Yb:FP glass | Nd:phosphate glass | Yb:YAG and FP glass option | Yb:S-FAP |
| Energy | 150 J | 100 J | 100 J | 100 J |
| Rep-rate | 0.1 Hz | 10 Hz | 10 Hz | 10 Hz |
| Average Power | 15 W | 1 kW | 1 kW | 1 kW |
| Pulse length | 150 fs | 10 ns | 1-10 ns | 3-10 ns |
| Peak Power | 1 PW | 10 GW | 10 GW | 10 GW |
| Output beam | 900 $cm^2$ | 12 $cm^2$ | 10 $cm^2$ | 15 $cm^2$ |
| Optical Efficiency | 10 % | 20 % | 20 % | 20 % |
| Additional capabilities | Configured as a short pulse system | • >100 GHz | • 1 ps option | • Frequency conversion<br>• 150 GHz<br>• 10 ps option |

# The Mercury Laser employs several key technologies

80 kW pump diode arrays

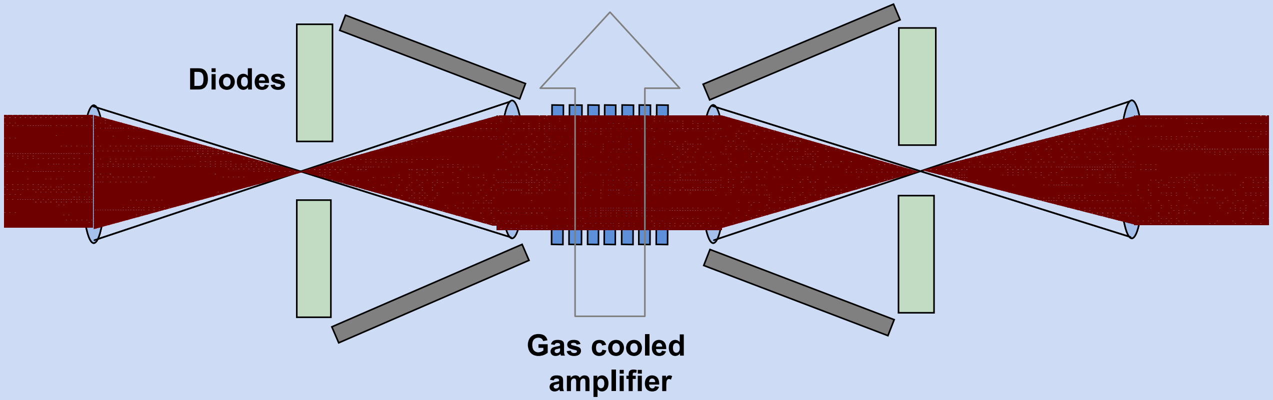


4x6 $cm^2$ Yb:S-FAP amplifier slabs

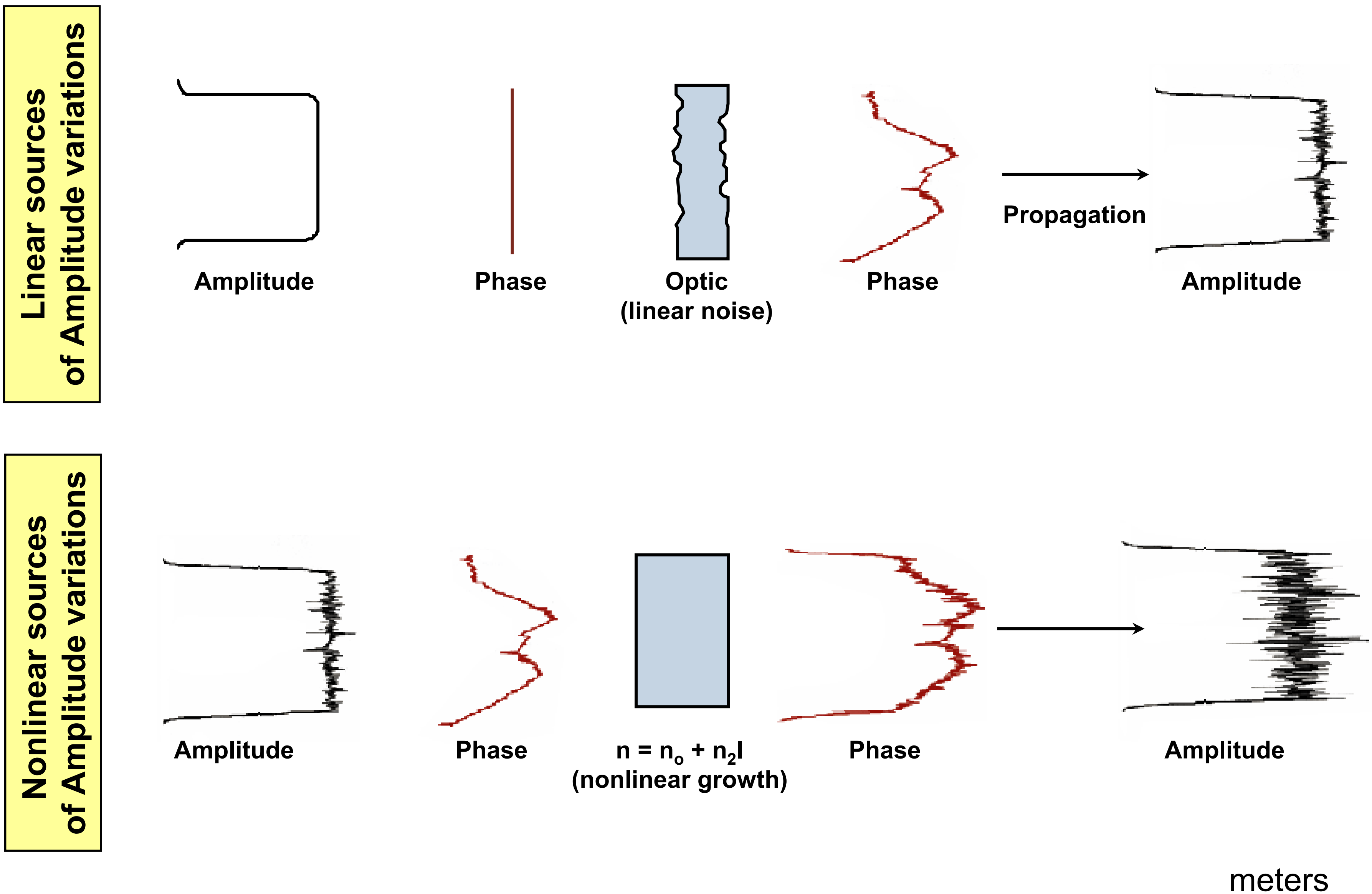


Mach 0.1 helium gas cooling

**Architecture: closely-spaced amplifier slabs**



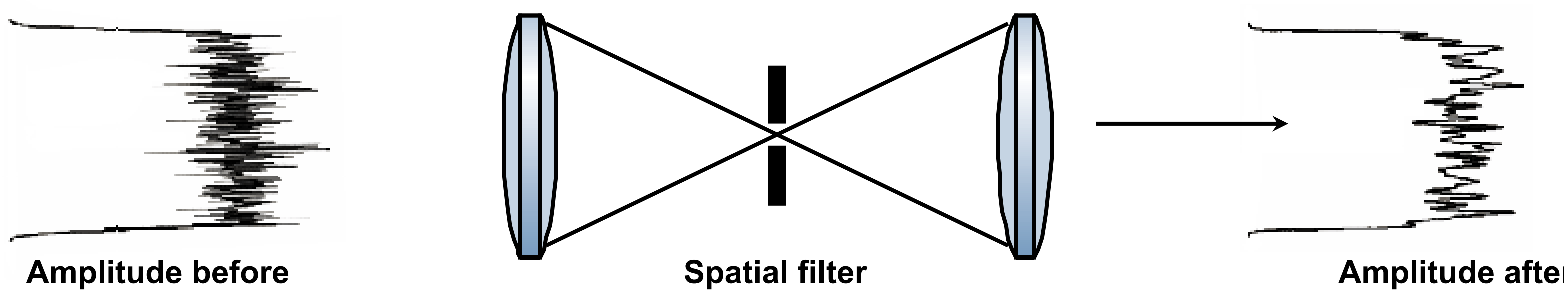
# Architecture, optical specifications, and nonlinear propagation are addressed



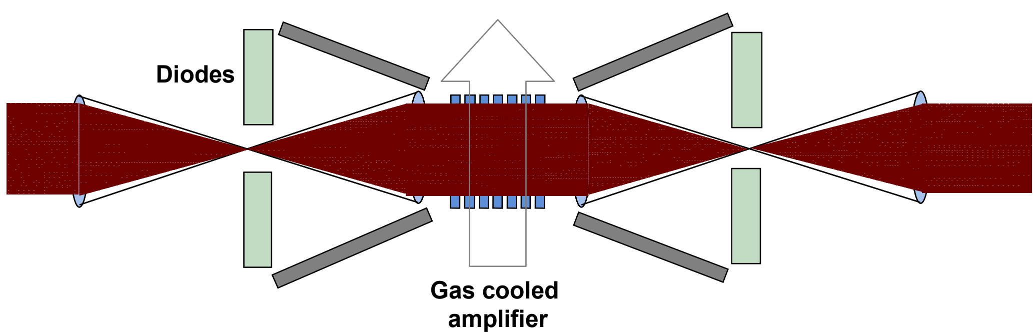
# There are several ways to reduce nonlinear growth of beam modulation

**Solutions:**

- Relay the location of near- field planes
- Filter fast growing spatial frequencies

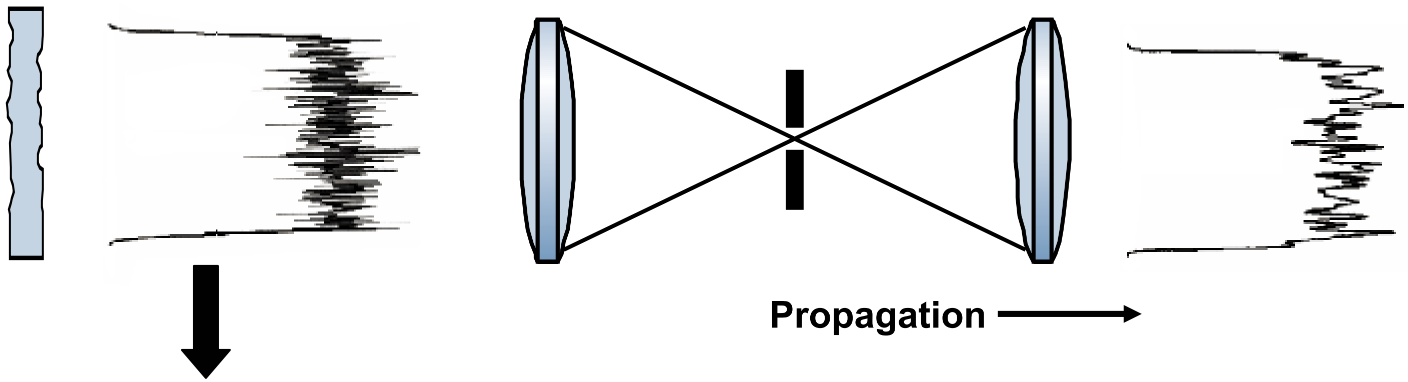



- Compact the optics near relay planes
- Minimize source terms through optical specifications

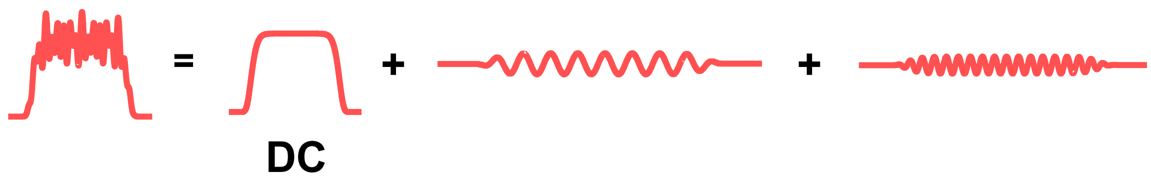


# Spatial frequencies convert from phase to amplitude at different propagation distances

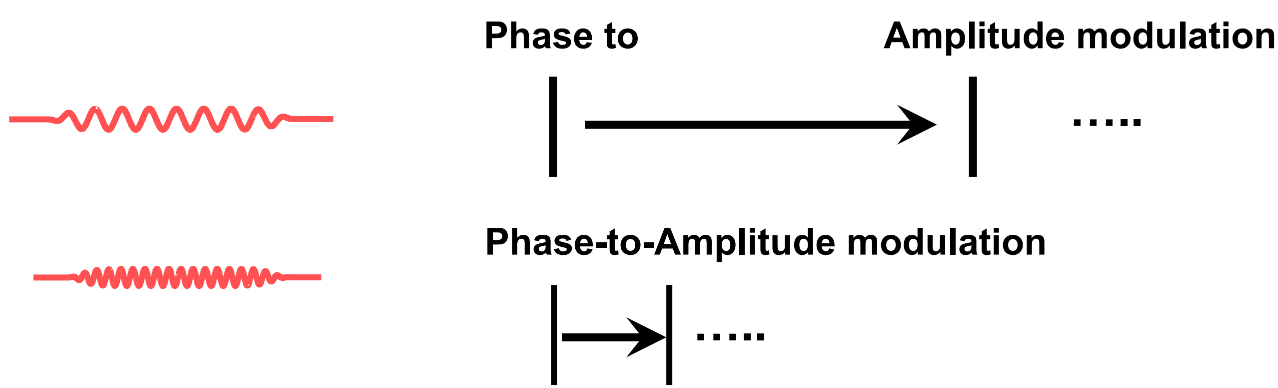
**Amplitude Modulation**




**Phase aberration frequency decomposition**



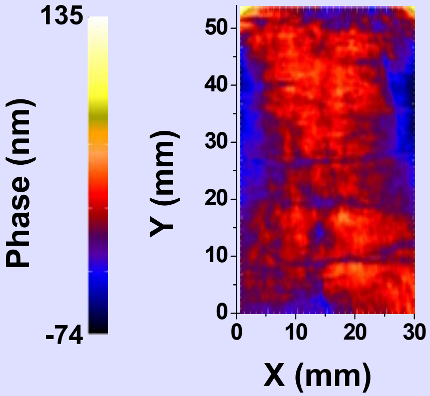

**Cycling of phase to amplitude modulation on beam**




**When propagating, the highest frequency phase aberrations are the first to appear as amplitude modulation**

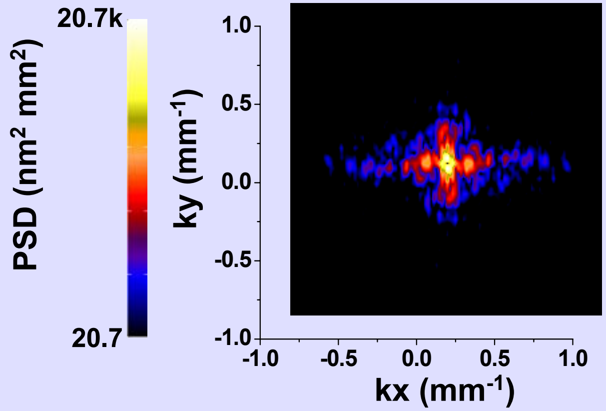
## 2-D Phase Map

$$\phi_{Phase}(x, y)$$



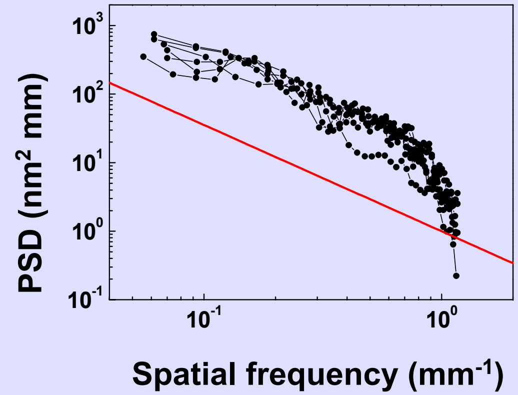

## 2D Power Spectral Density

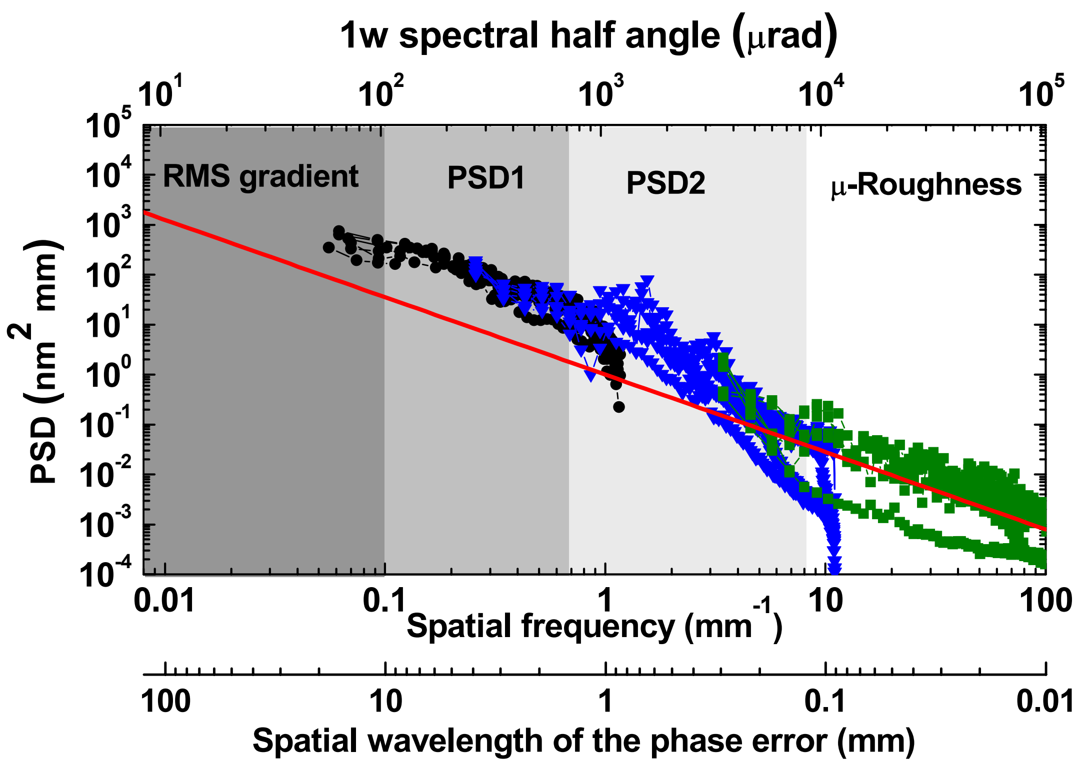
$$PSD(\nu_x, \nu_y) = \frac{\left|\Phi(\nu_x, \nu_y)\right|^2}{\Delta\nu_x \Delta\nu_y}$$



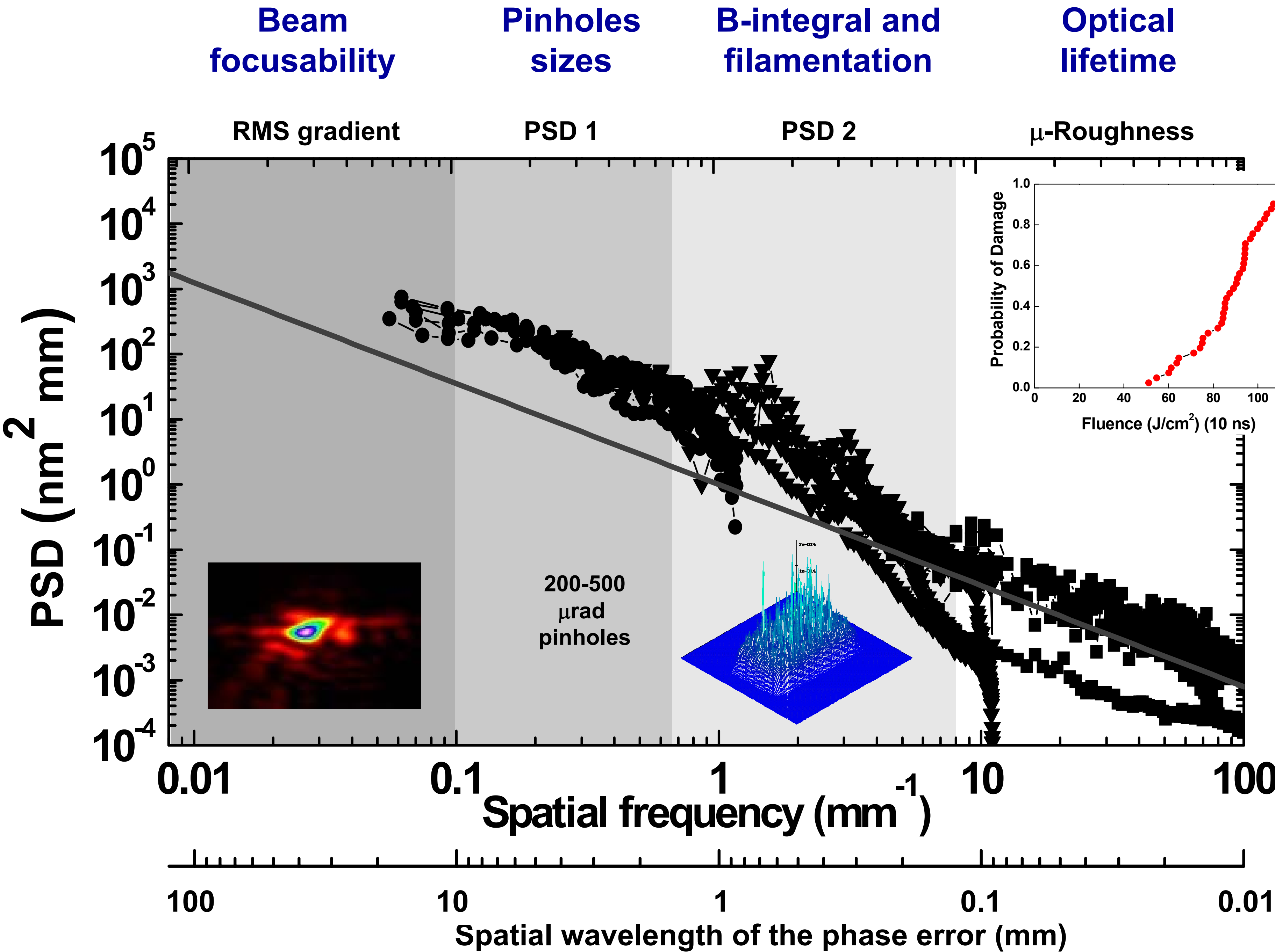

## 1 D Power Spectral Density

$$PSD(\nu_x) = \int PSD(\nu_x, \nu_y) d\nu_y$$



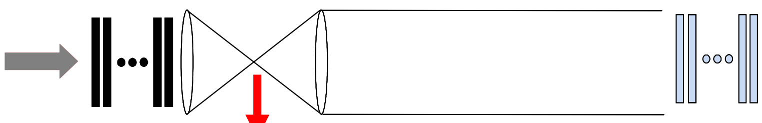



*Optical specifications can drive:*



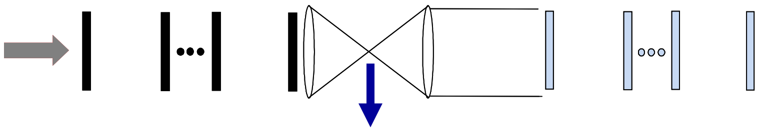
# The closely space architecture reduces beam intensity on pinholes and optics

**Closely spaced architecture**

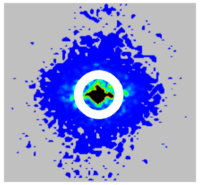


**Relay planes**

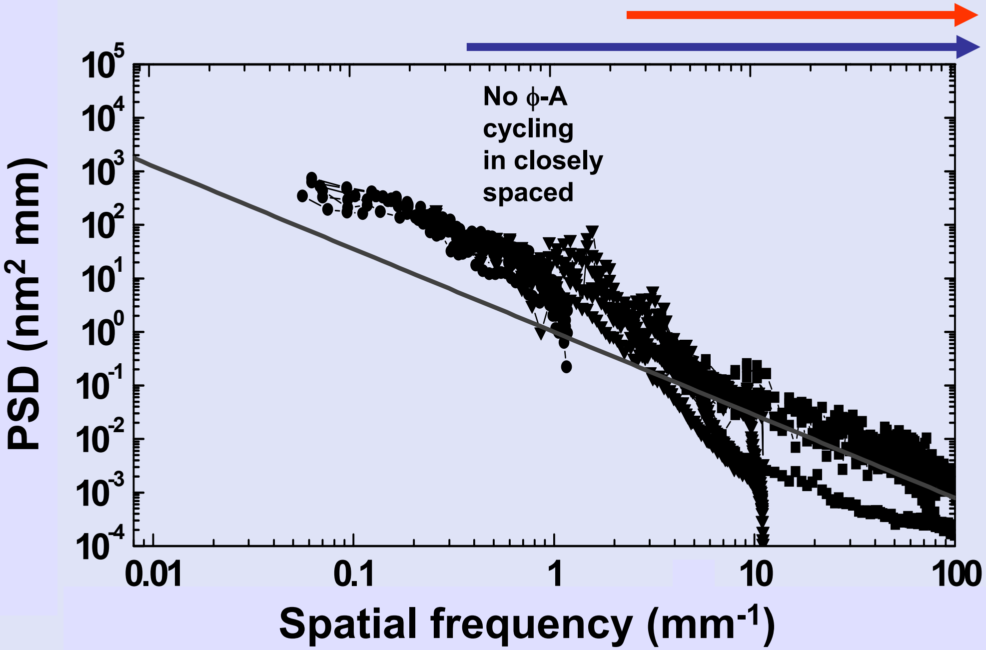
**Widely spaced architecture**



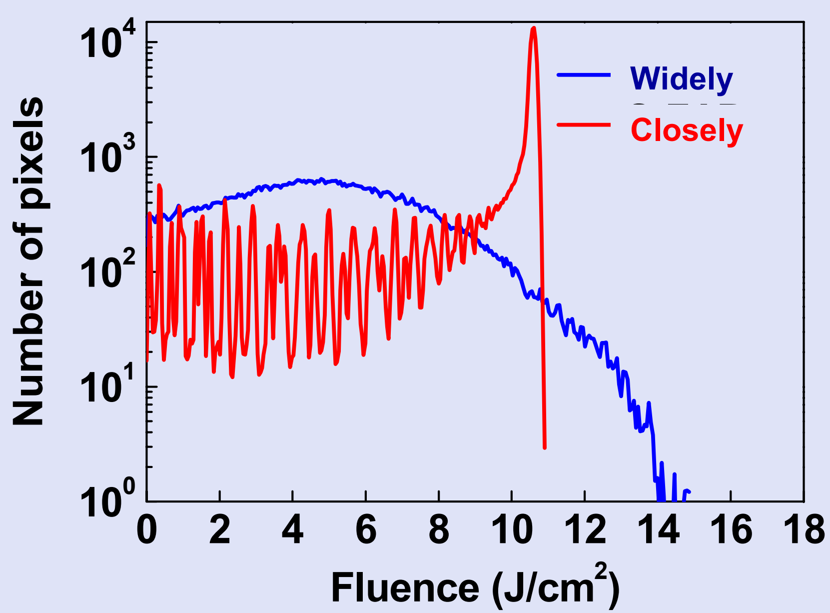
**Pinhole intensity distributions**



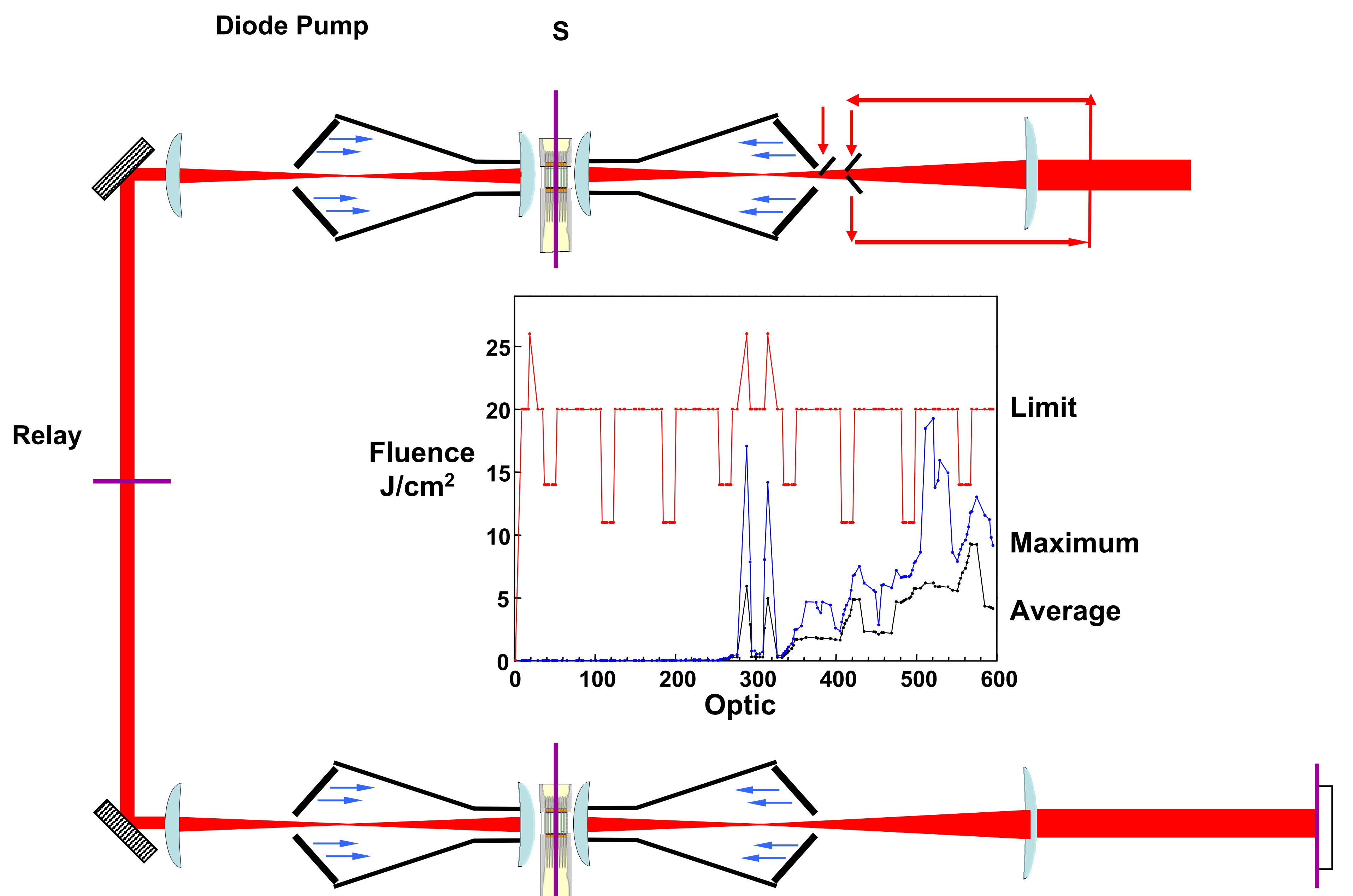
**Noise term**




**Near field histogram**



# On the basis of the reduced non-linear growth, Mercury was configured with closely spaced slabs

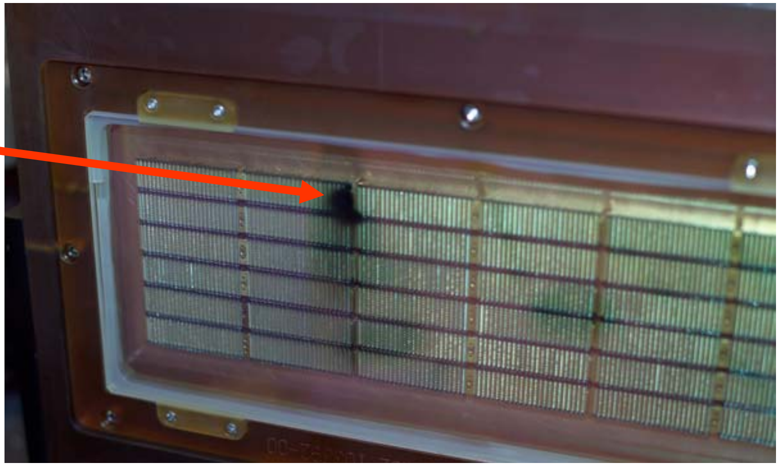


# The Mercury Laser is currently running with all 8 diode arrays

**2.3 kW tiles (23 bars)**

**80 kW arrays (36 tiles)**

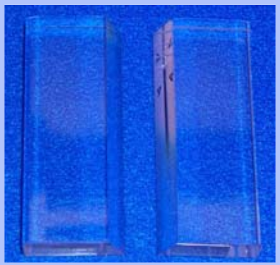
- During laser alignment a diode tile contact failed
- Analysis indicated contact fatigue occurred during installation
- New tooling is being developed
- Image monitoring analysis has been added



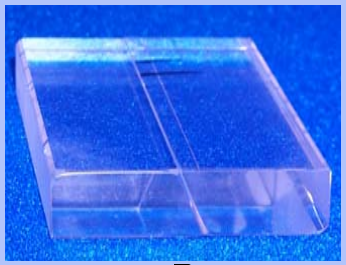
# There are 23 slabs in fabrication to fully populate the amplifiers and provide 9 spares

***Fabrication steps***

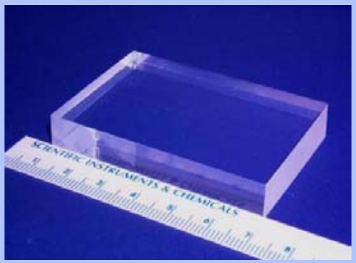
G
4



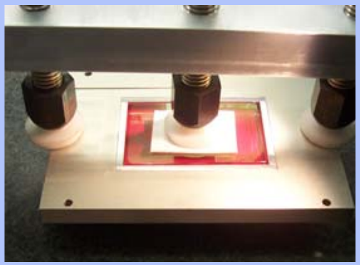
S
6



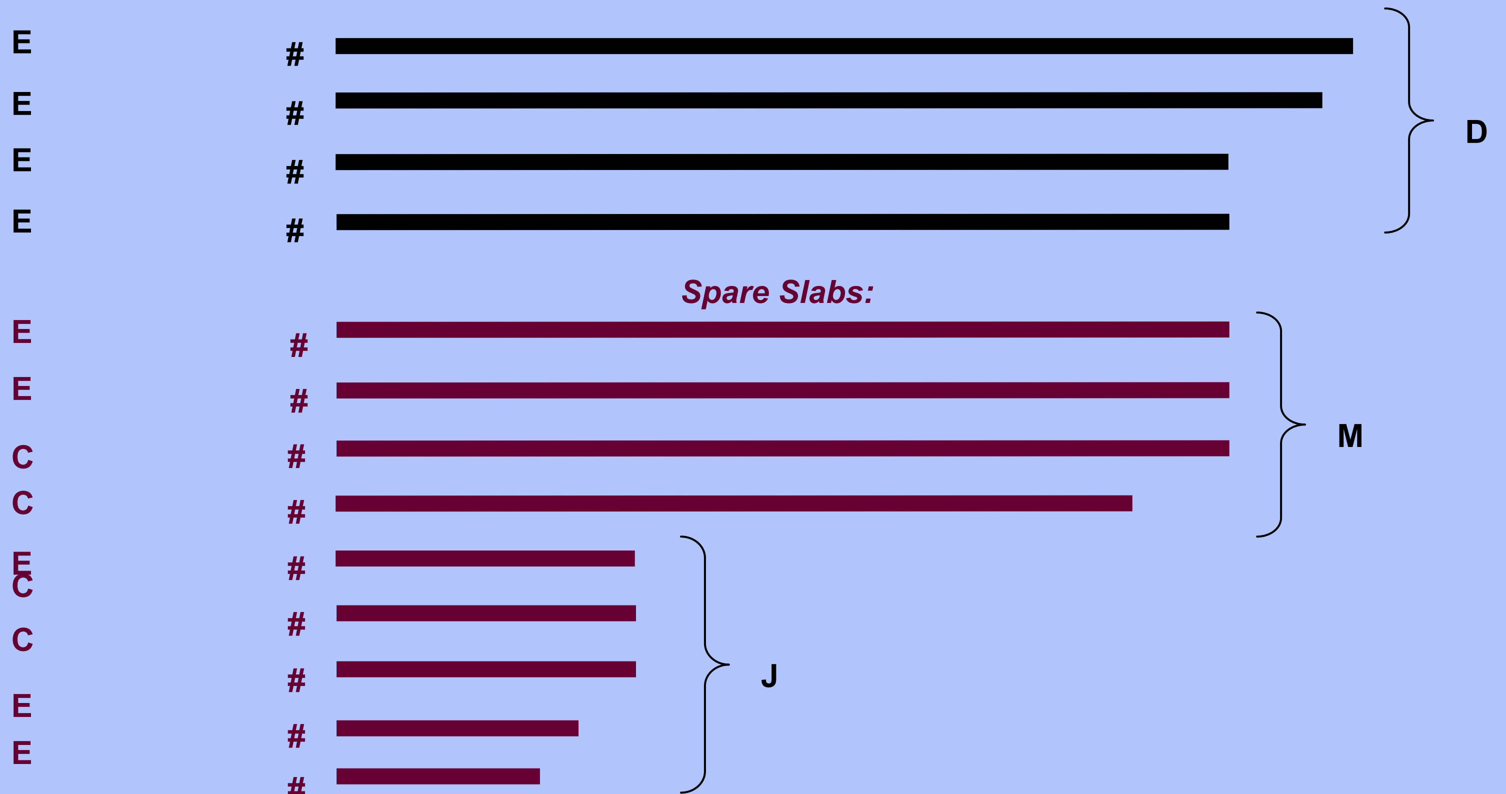
B
1




S
9

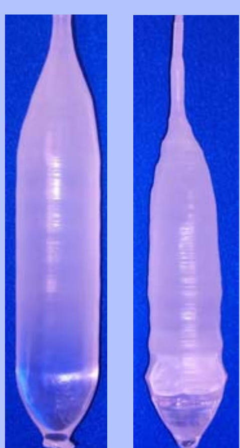


A
2






**Before upgrade**



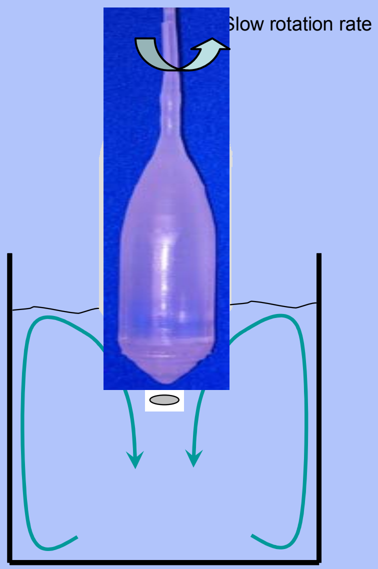
**After**

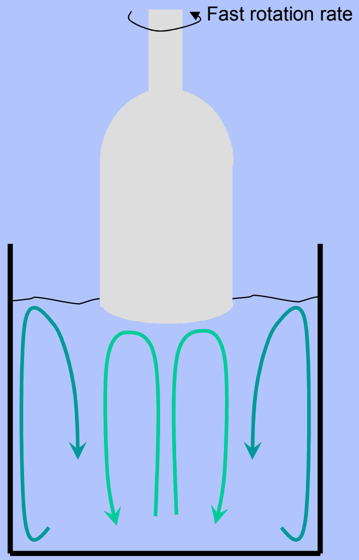
**All three LLNL crystal growth stations are operating**

**Before upgrade**

**After**

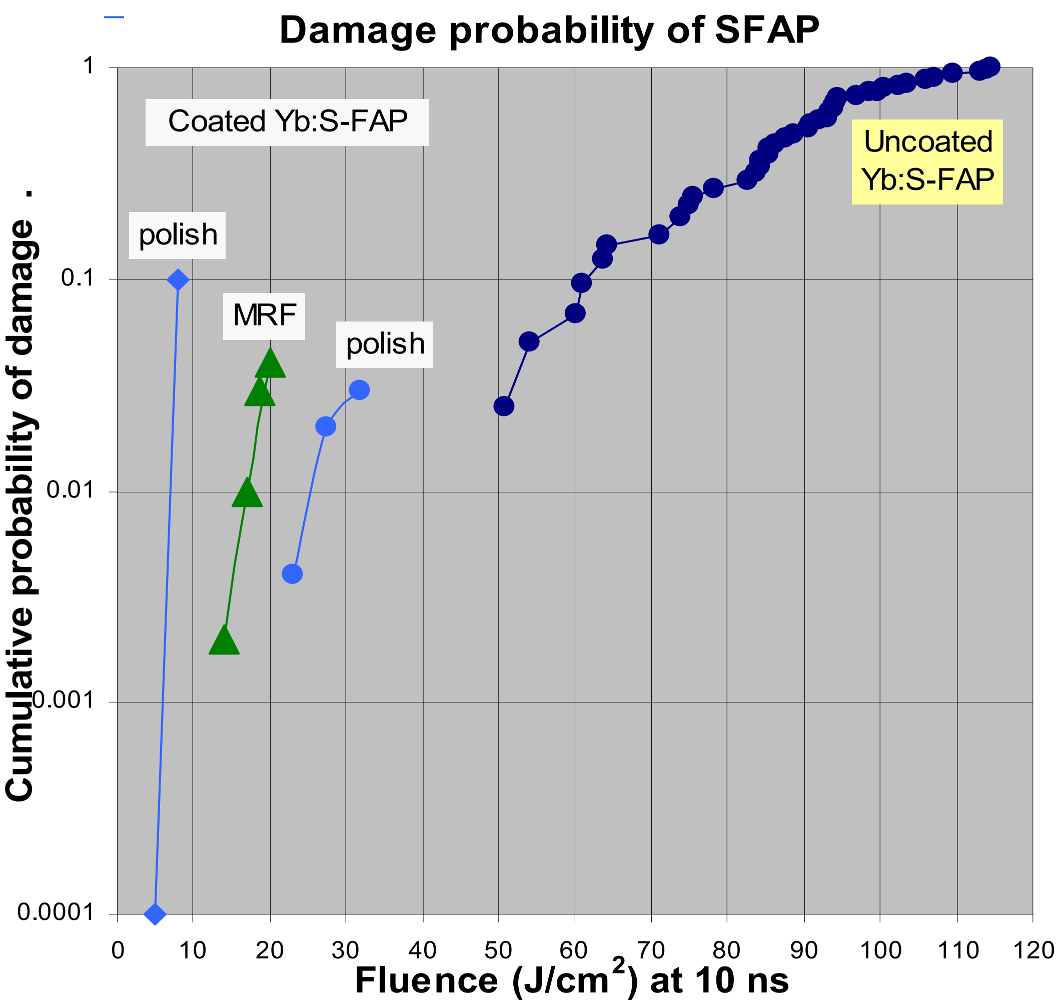
# Eight 6.5 cm diameter boules have been were grown at




**1st flat interface attempts**

# The impact of MRF finishing on 1ω laser damage threshold of coated S-FAP crystals is being evaluated




## Damage Data Growth Experiments

***MRF***

**Initiation: 20 J/cm$^2$**

**Additional sites: 20 J.cm$^2$**

**Rapid degradation : 27.5J/cm$^2$**

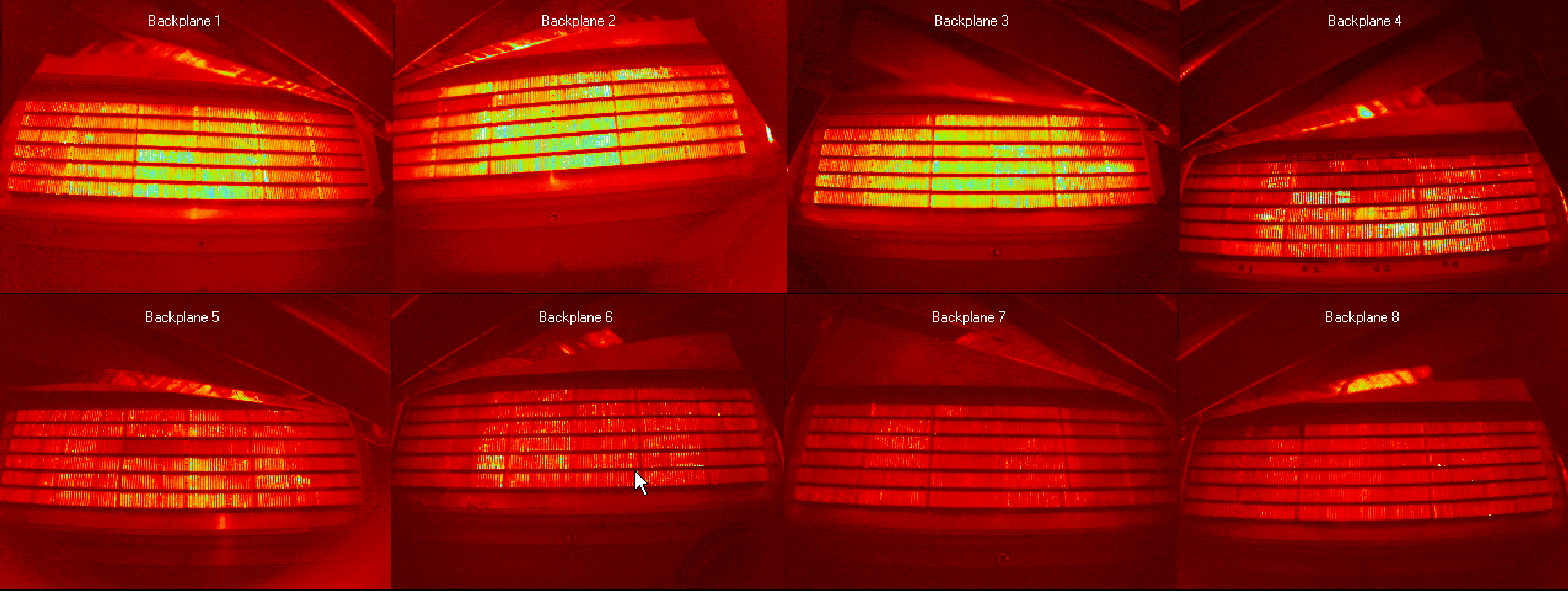
***Conventional Polish***

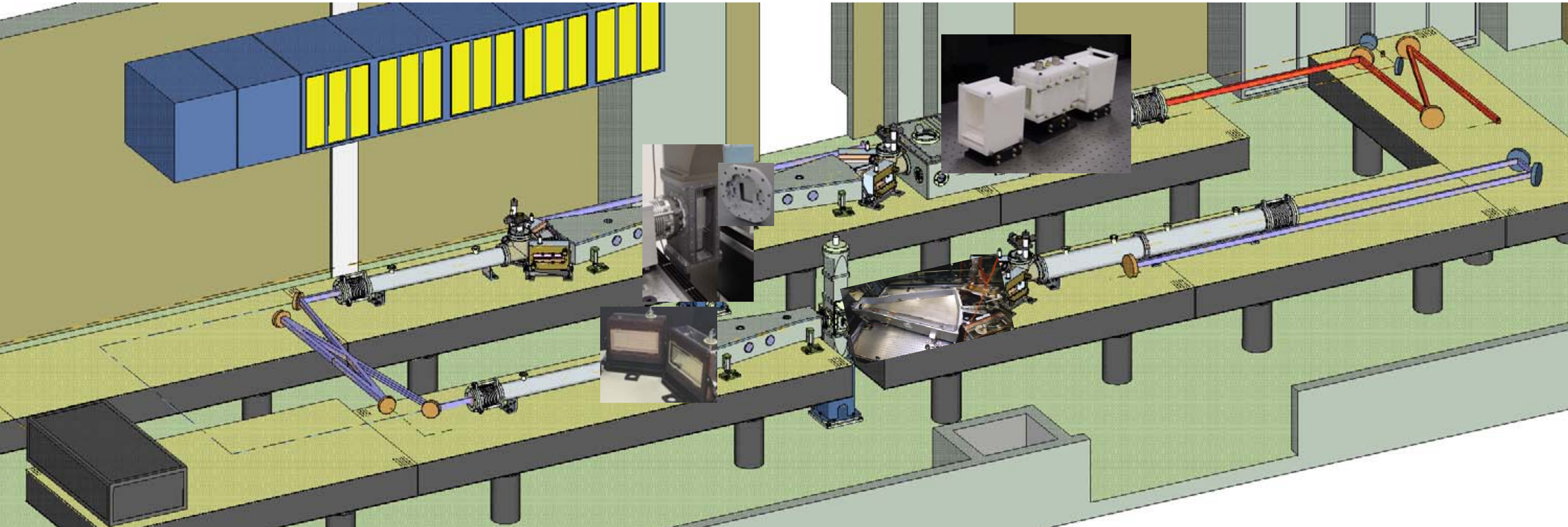
**Initiation: 20 J/cm$^2$**

**Additional sites: 27 J.cm$^2$**

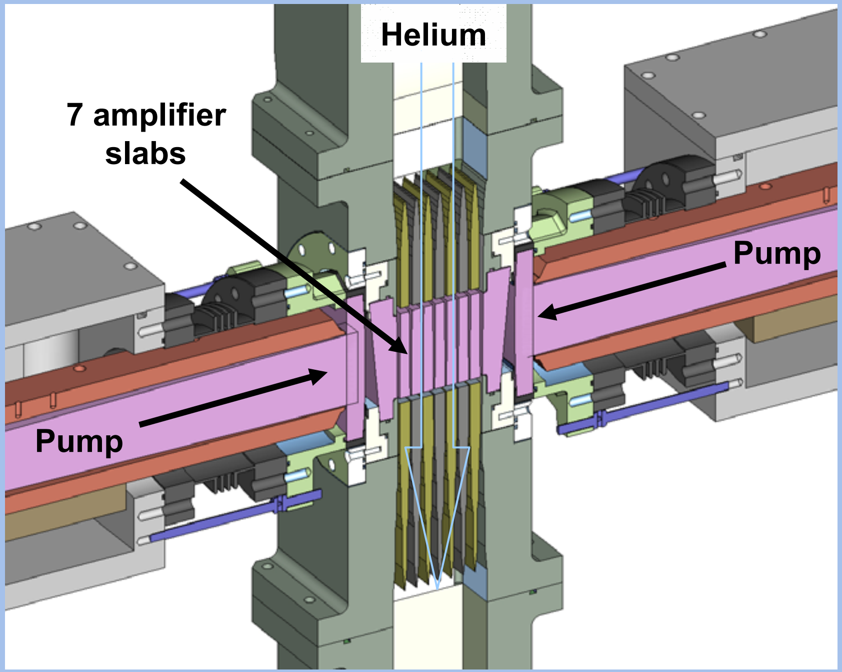
**Rapid degradation: 30J/cm$^2$**

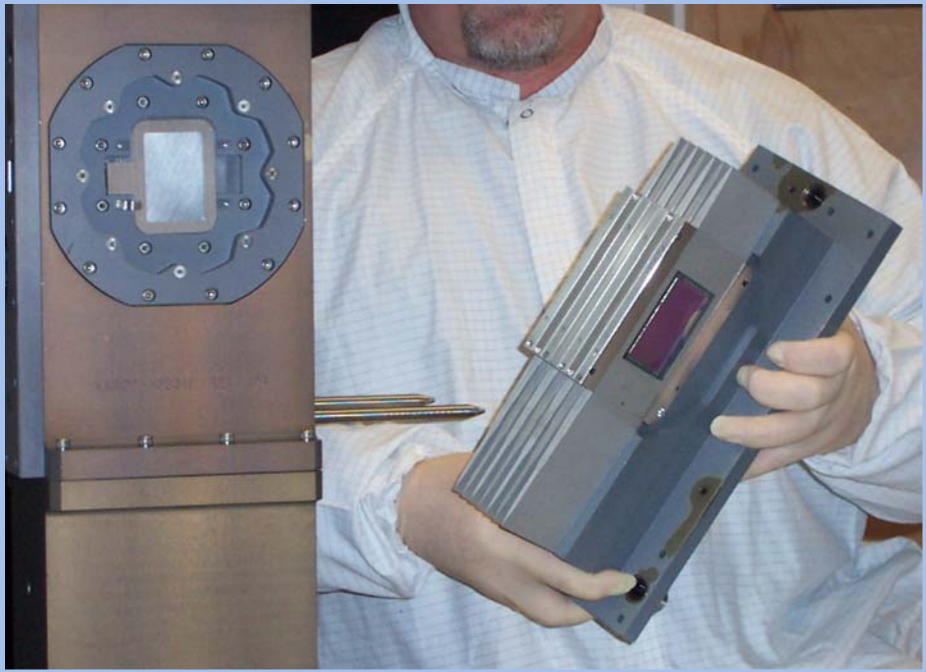

Newport

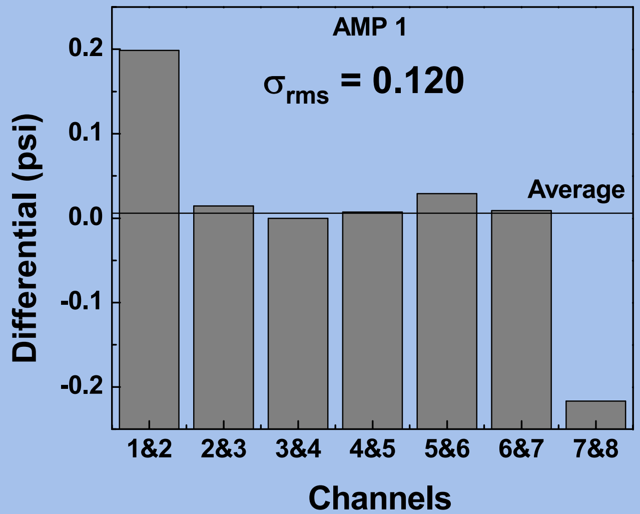

Backplane 1
Backplane 2
Backplane 3
Backplane 4
Backplane 5
Backplane 6
Backplane 7
Backplane 8

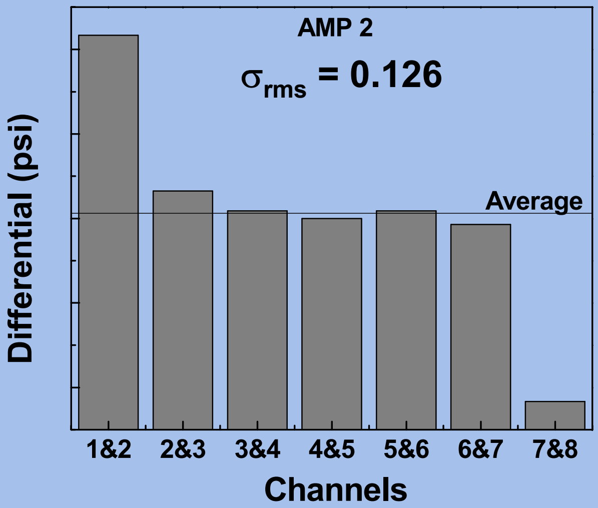


# Both amplifiers have been deployed with helium gas cooling

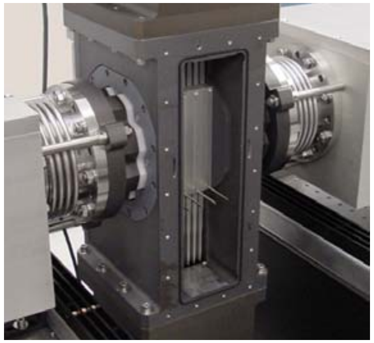




**Amp 1**



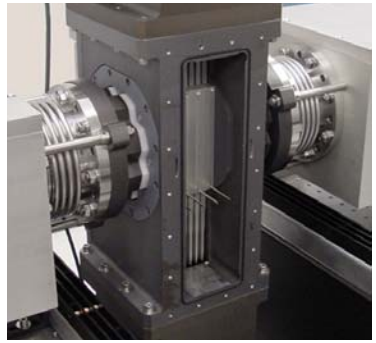
**4 gain slabs**

**7 blanks**

**4 gain slabs**

**5 gain slabs**

**Amp 2**

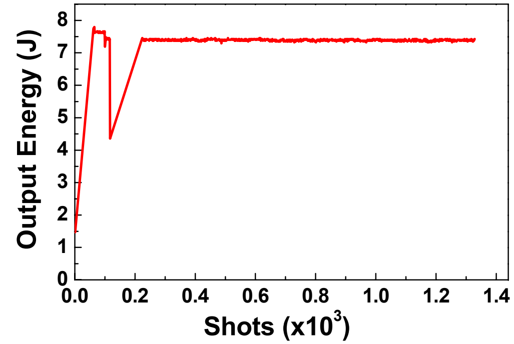


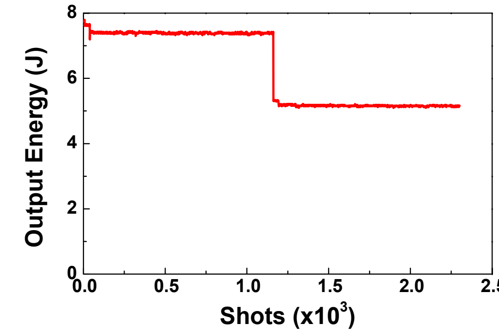
**7 blanks**

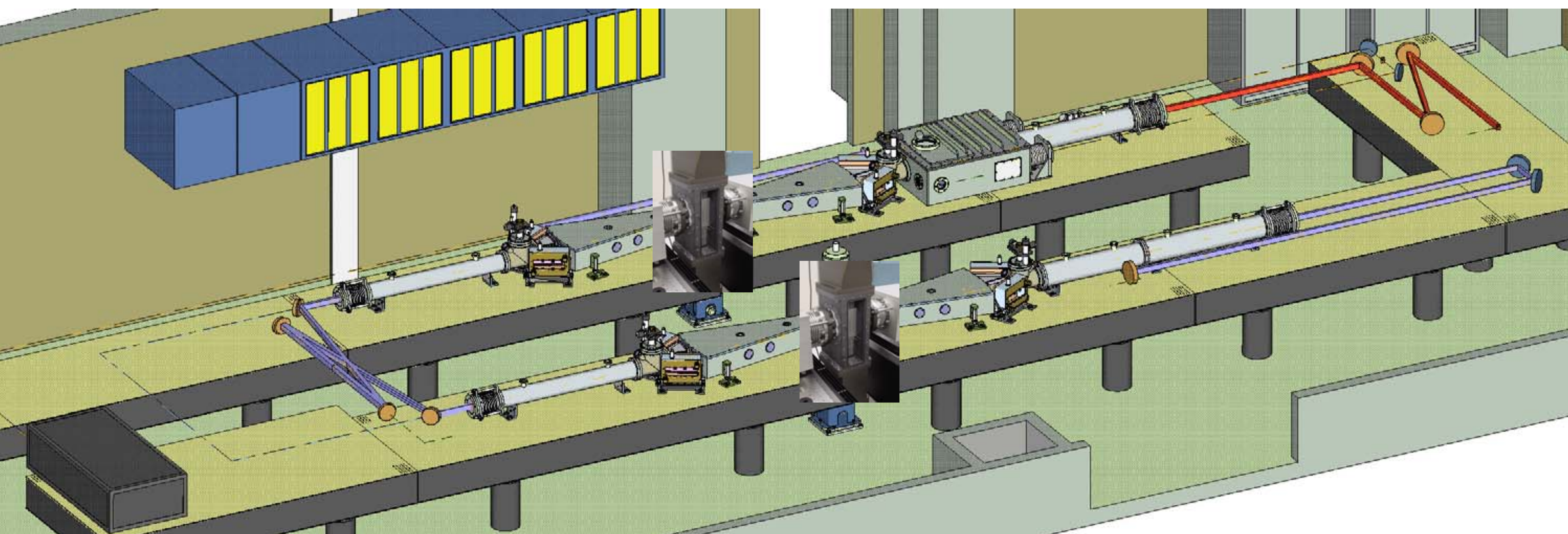
**4 gain slabs**

**4 gain slabs**

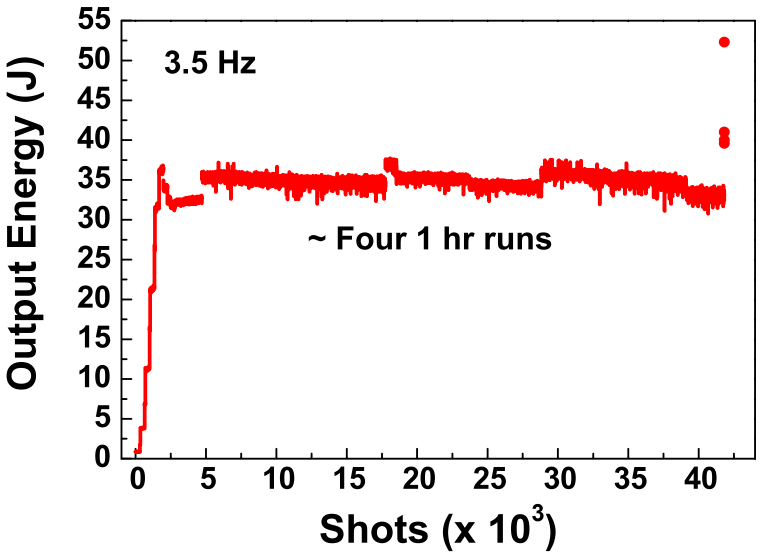
**5 gain slabs (in progress)**

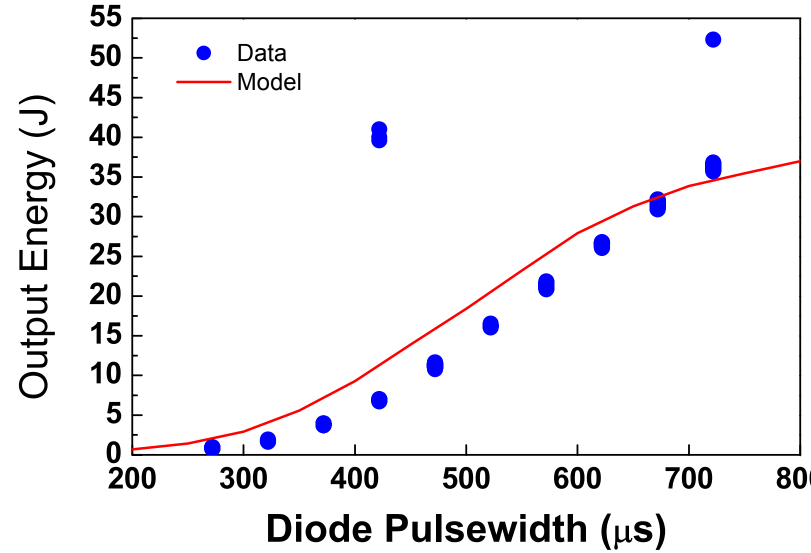


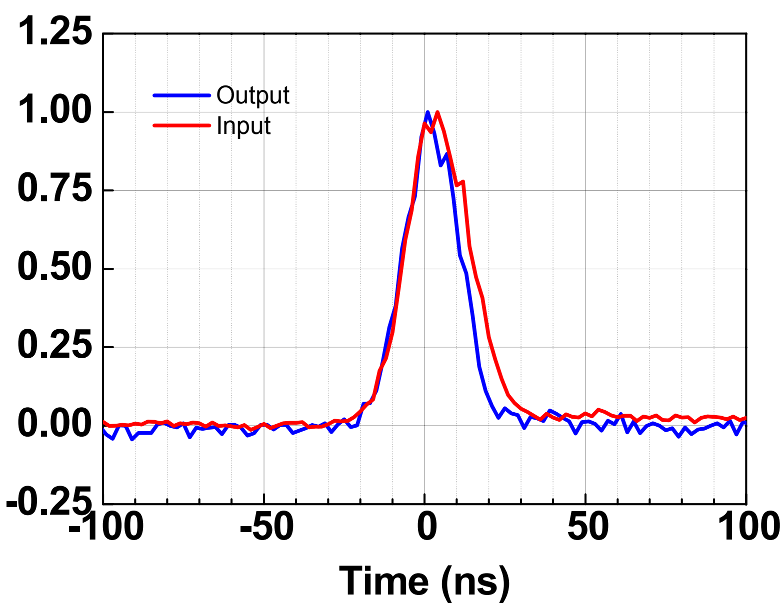



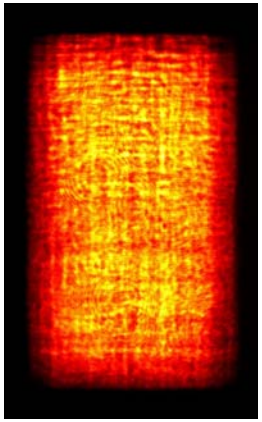
# Mercury 8 Slab Campaign Summary



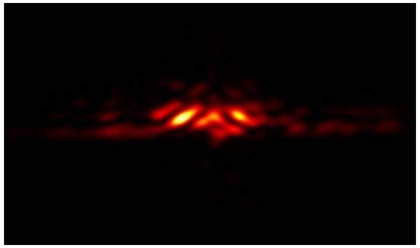



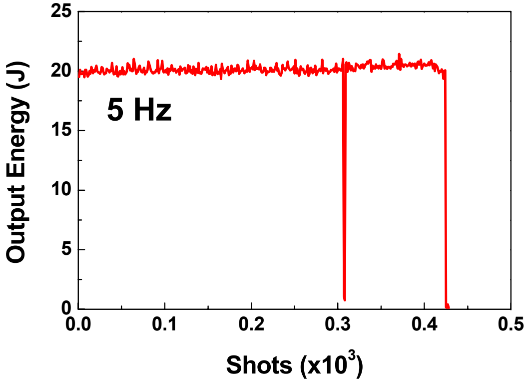

Output
Near field

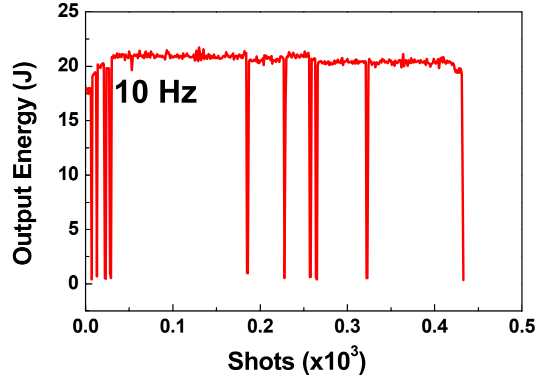


Output
Far Field
76% in 5X diffraction
limited beam

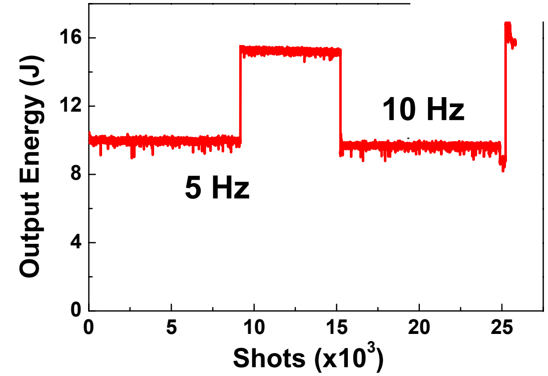


## NRL: Dec 2002

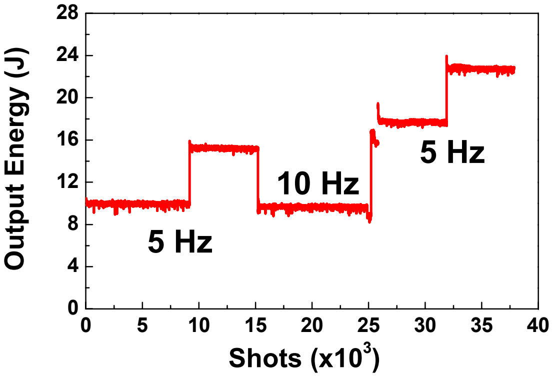


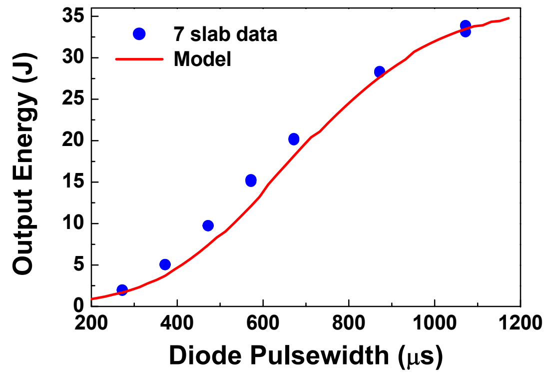




## Sandia: Apr 2003

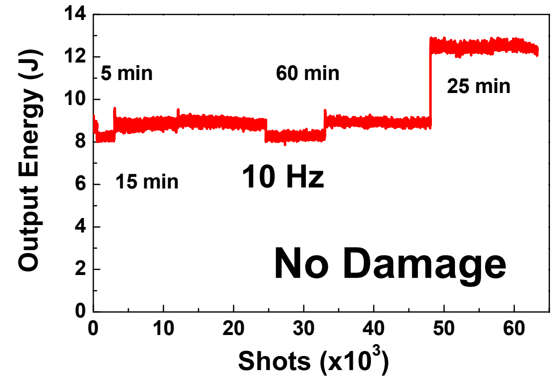



## Wisconsin: Sep 2003



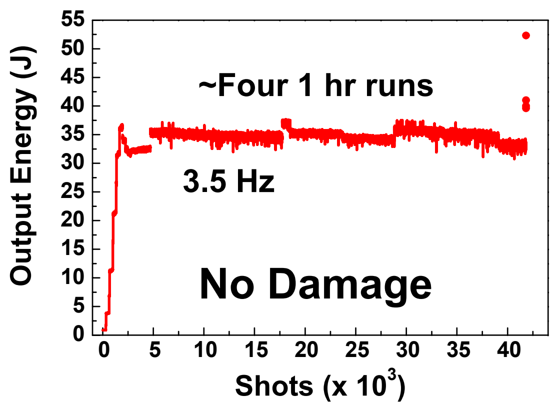



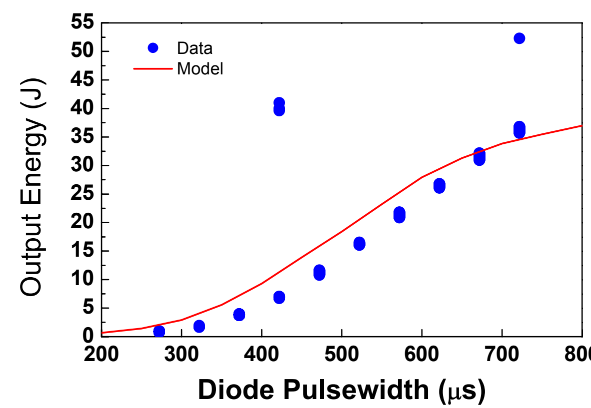

## Atlanta: Feb 2004



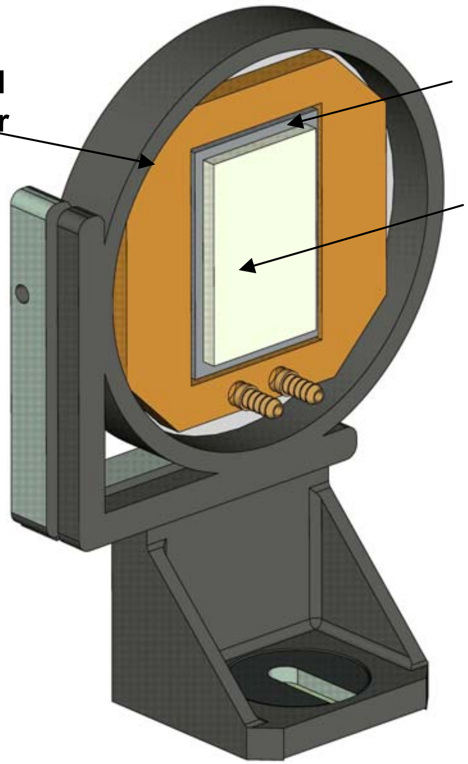

## Princeton: Oct 2005

## UCLA: June 2005 2nd amp build up

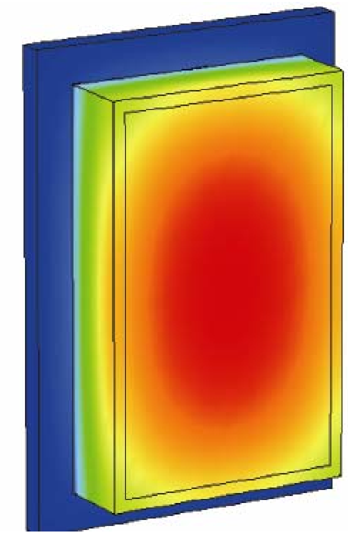


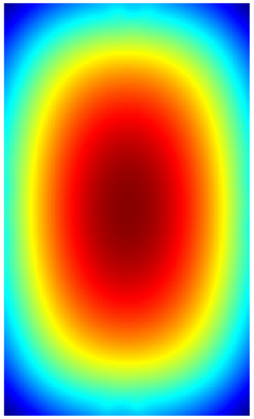



# We have completed our thermal modeling of the frequency converter design



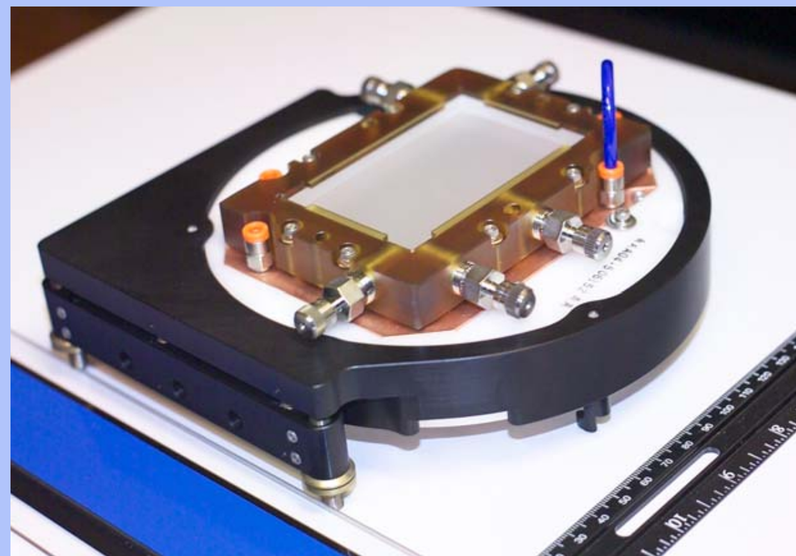

YCOB: 50J, 10Hz, 1.58 cm



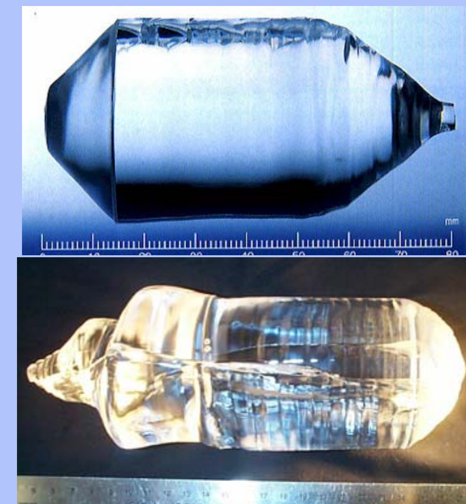



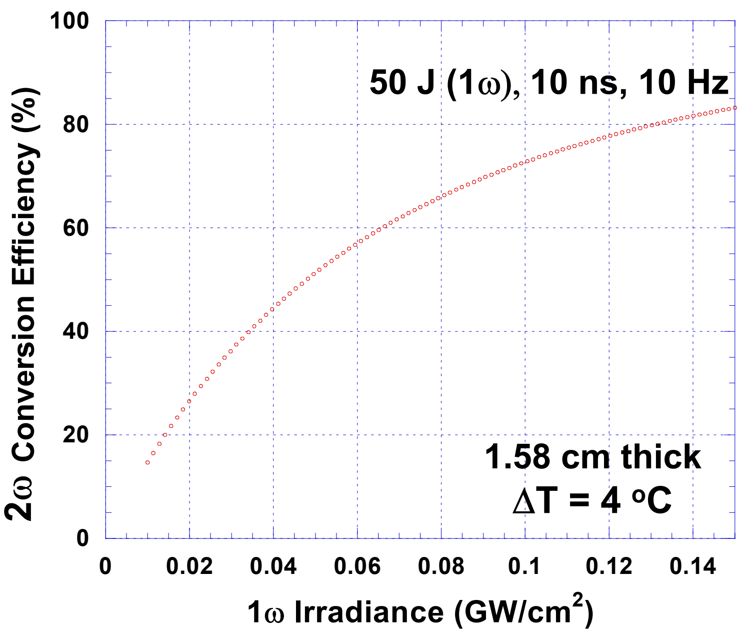

| | Deff (pm/V) | Growth Achieved (dia. cm) | Angular Acceptance (mrad-cm) | Wavelength Acceptance (nm-cm) | Temperature Acceptance (°C-cm) |
|---|---|---|---|---|---|
| BBO | 2.05 | 2 | 0.7 | 2.15 | 51 |
| KDP | 0.26 | 50+ | 1.25 | 19.7 | 11.3 |
| DKDP | 0.23 | 50+ | 1.34 | 5.2 | ~11 |
| YCOB | 1.1 | 8.5 | 1.22 | 1.15 | 40 |

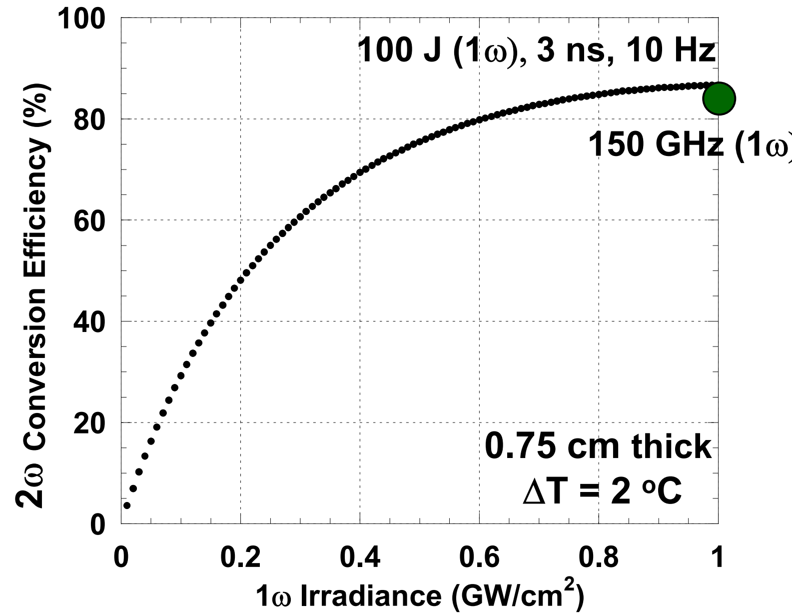
# We have begun building the frequency conversion modules



8 -10 cm long YCOB boules

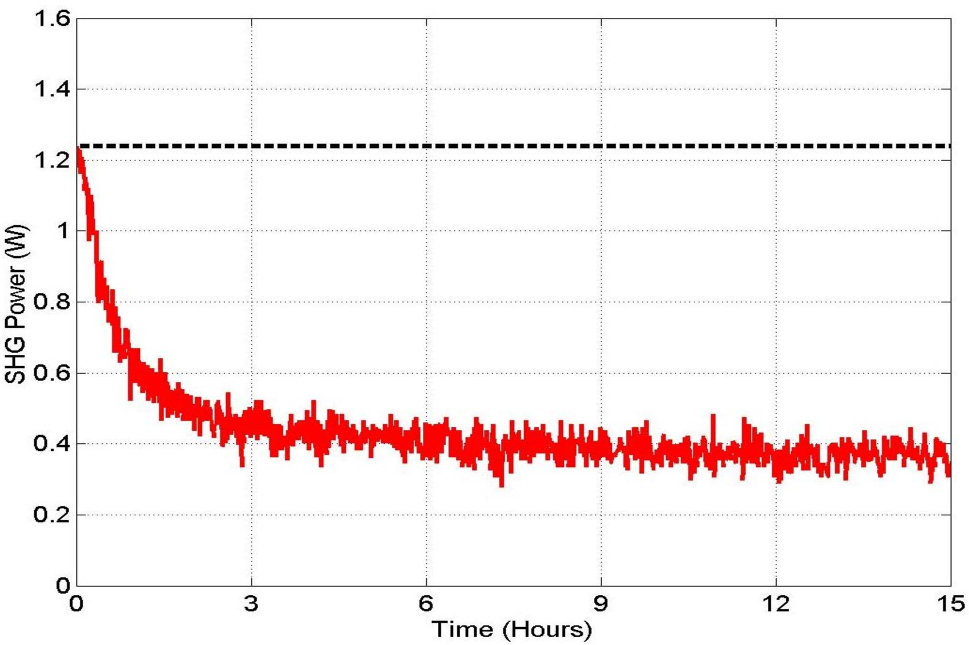




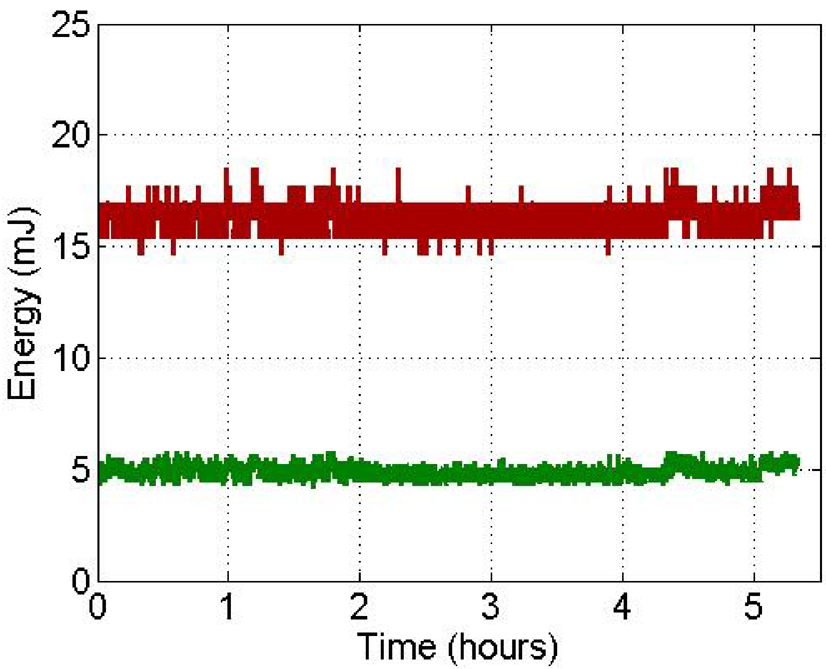



# YCOB lifetime experiments are being performed to confirm long term operation is possible without degradation in efficiency

**PPKTP**




**YCOB**

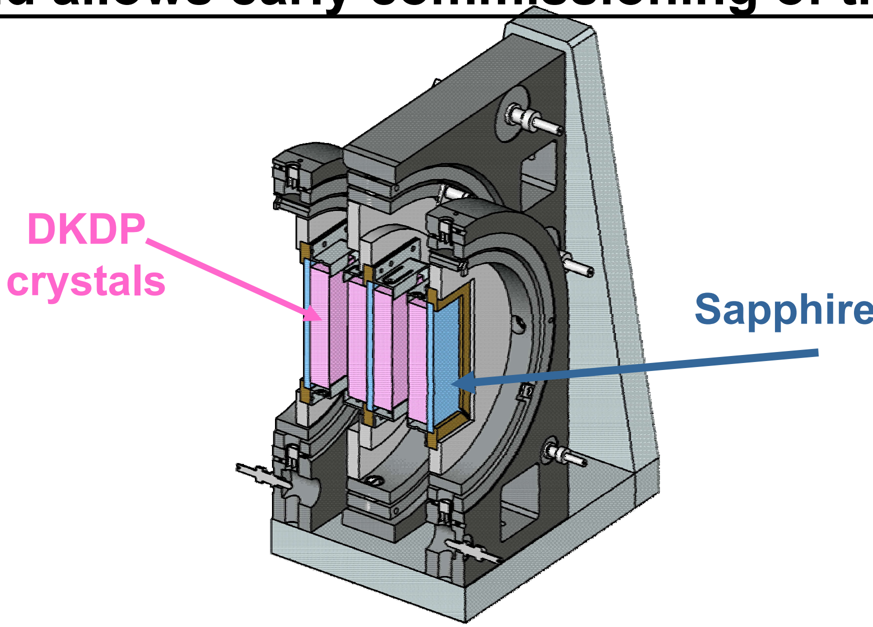


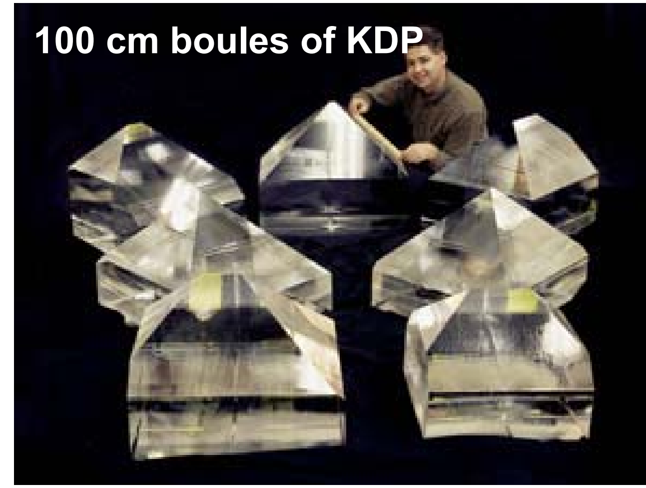

**PPKTP exhibits photo-degradation:**

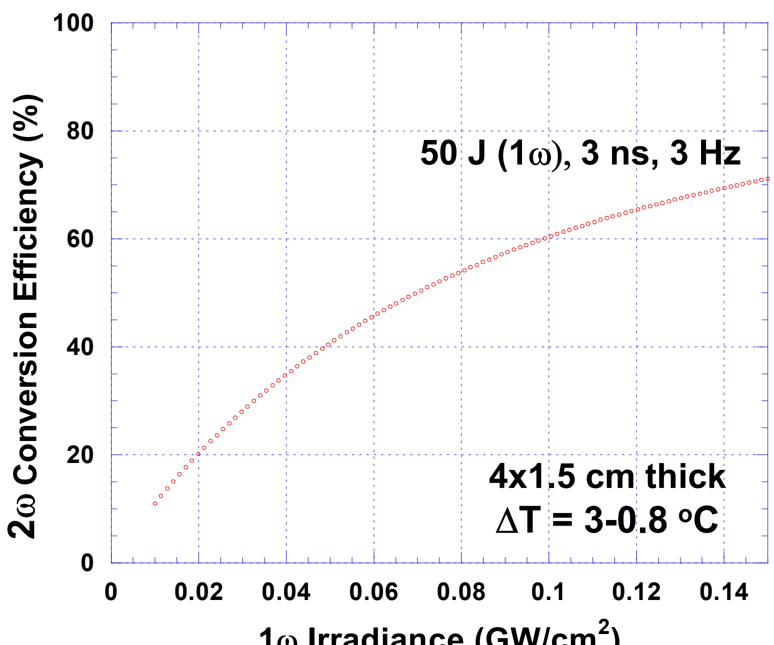
- **color center formation ($Ti^{4+}$ reduced to $Ti^{3+}$)**
- **reduced conversion efficiency**

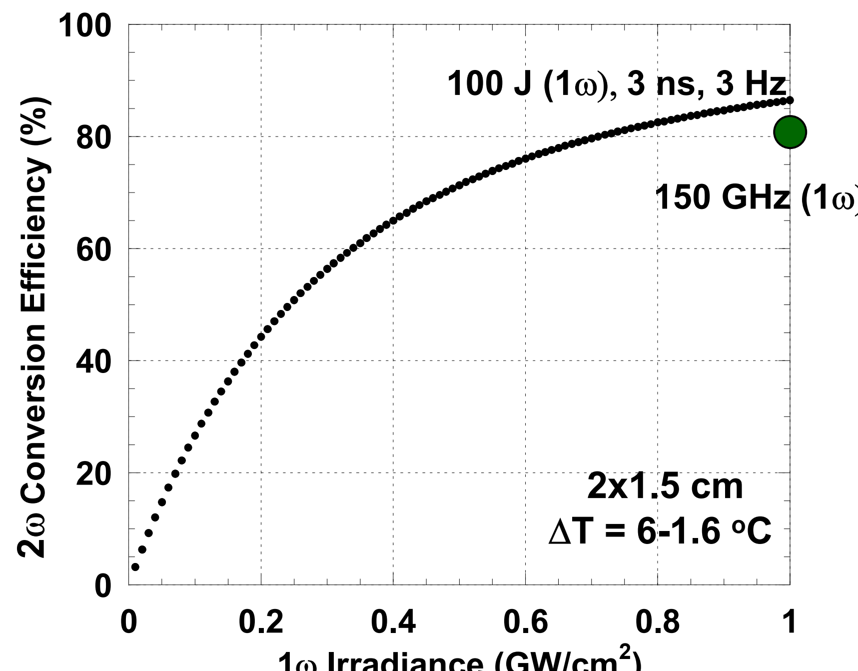
**YCOB exhibits no degradation after 6 hours**

# DKDP is being persued in parallel with YCOB and allows early commissioning of the cooling hardware



# Outline

- Project Overview (We are leveraging off of other DPSSL efforts)
  - Mercury Laser performance goals
  - International 100 J class systems
- Laser architecture (Architecture incorporates robustness)
  - Design
  - Performance
- System performance (System completed and several 1 hour runs accomplished)
  - Diode arrays
  - Crystalline gain media
  - Gas cooled amplifiers
  - Laser operations
- Upcoming activities and other topics
  - Frequency conversion (Assembly of hardware begun)
  - Front End
  - IRE

M

C

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Laboratory for Laser Energetics

CEA (Bordeaux)
Northrop-Grumman
Onyx Optics
Schott Glass Technologies
Spectra Physics
Quality Thin Films
Zygo
Photonic Crystals

Coherent
Directed Energy