



**American Society of Naval Engineers (ASNE)  
Combat Systems Symposium 2012  
Arlington, VA**

Balancing Capacity vs. Capability

**Laser Weapons for Naval Applications**

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# Report Documentation Page

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# Outline

- Background
- Laser candidates
  - Free electron lasers
  - Solid state lasers
- Additional capabilities
  - Power beaming



# Laser Lethality

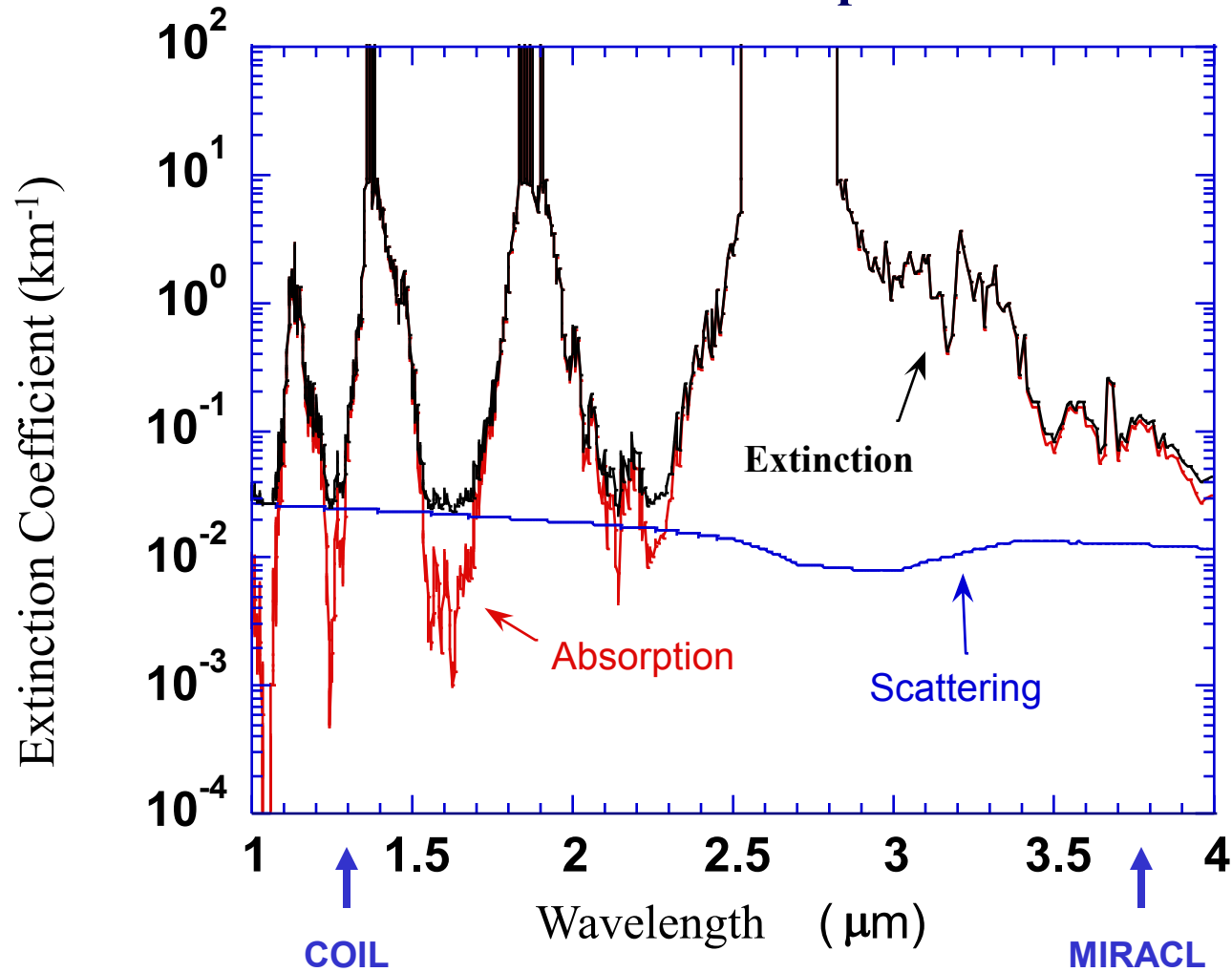
- Thermally ablating 1/4 pound of target material requires  $\sim 1.3$  MJ of laser energy
- 1 MJ is equivalent to  $\sim 1/2$  pound of explosive
- 100 kW of absorbed laser power for 2 sec ablates  $\sim 20$  grams ( $\sim 8$  pennies)
- For an engagement time of 5 sec the required laser power is  $> 250$  kW



# Capabilities of Laser Weapons

- Agile speed of light delivery (instantaneous)
- All electric energy source (deep magazines)
- Long range targeting
- Multi-targeting
- Compatible with all electric ships

## Extinction Coefficient vs Wavelength Maritime Atmosphere



**Maritime  
Windows**

- ~ 1 μm
- ~ 1.25 μm
- ~ 1.6 μm
- ~ 2.1-2.3 μm

Generated by MODTRAN



# Laser Systems for Naval Applications

- Free Electron Lasers

- Jefferson Lab.  $P > 14$  kW,  $\lambda \sim 1.6$   $\mu\text{m}$

- Solid State Lasers

- IPG fiber lasers, 10 kW/fiber

- Northrop Grumman JHPSSL

- 100 kW (2011), 7 tiles

- $\lambda = 1.06$   $\mu\text{m}$  ( $\text{N}_d$ :YAG)

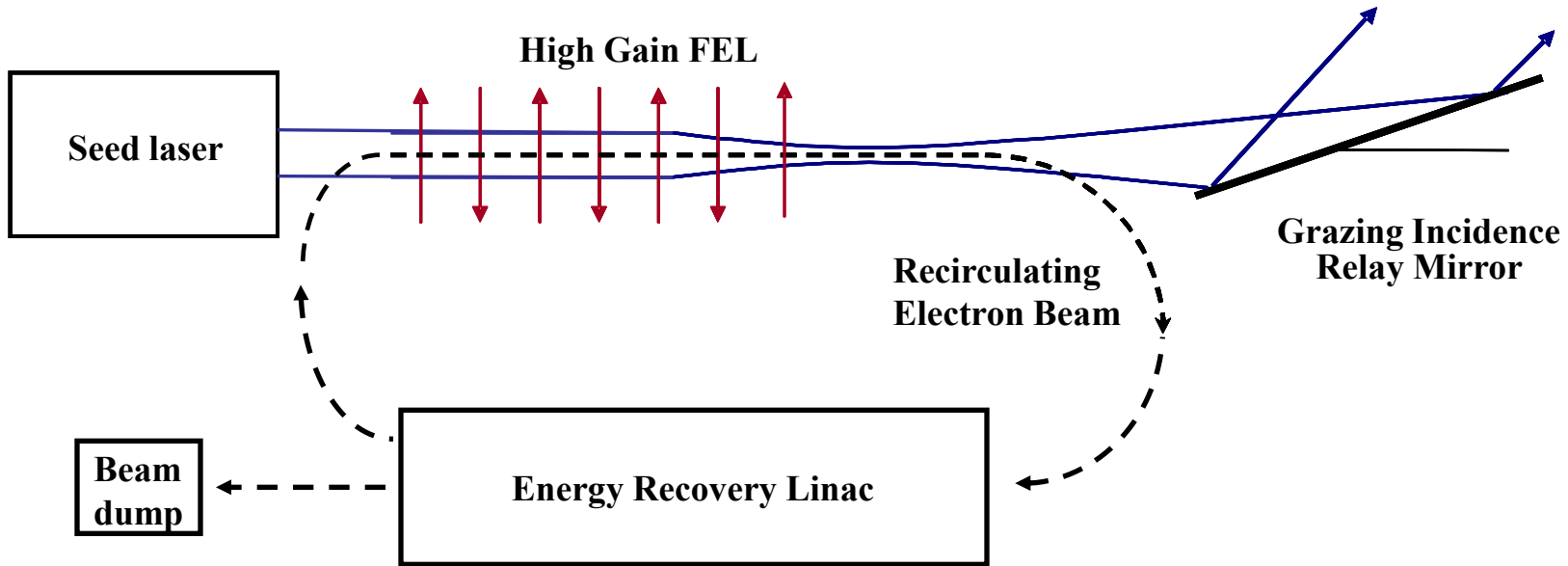


# Free Electron Lasers

- High average power capability
- Output wavelength is tunable  
(can operate in atmospheric window)
- Wall-plug efficiency  $\sim 10\%$  (potentially)
- Dimension  $\sim 4\text{m} \times 4\text{m} \times 30\text{m}$ , for 100kW to  $\sim 1\text{MW}$
- Ship power requirements  $> 10\text{ MW}$   
(engagement time  $\sim 10\text{s}$  of minutes)



# High-Gain, High Efficiency Free Electron Laser



- Electrons undulate in wiggler field and bunch at optical wavelength
- Optical radiation is amplified

Example:  $\lambda_w = 3\text{ cm}$ ,  $E_b = 80\text{ MeV}$   $\lambda \approx 1\ \mu\text{m}$

Goal:  $\langle P \rangle \sim 1\text{ MW}$   $\lambda = 1\ \mu\text{m}, 1.6\ \mu\text{m}, 2.3\ \mu\text{m}$



## Fiber Lasers

- Compact

- High-Power  $P_{\text{fiber}} = \begin{cases} 8\text{kW}, & \text{commercially available} \\ 10\text{kW}, & \text{state-of-the-art} \end{cases}$

- Robust

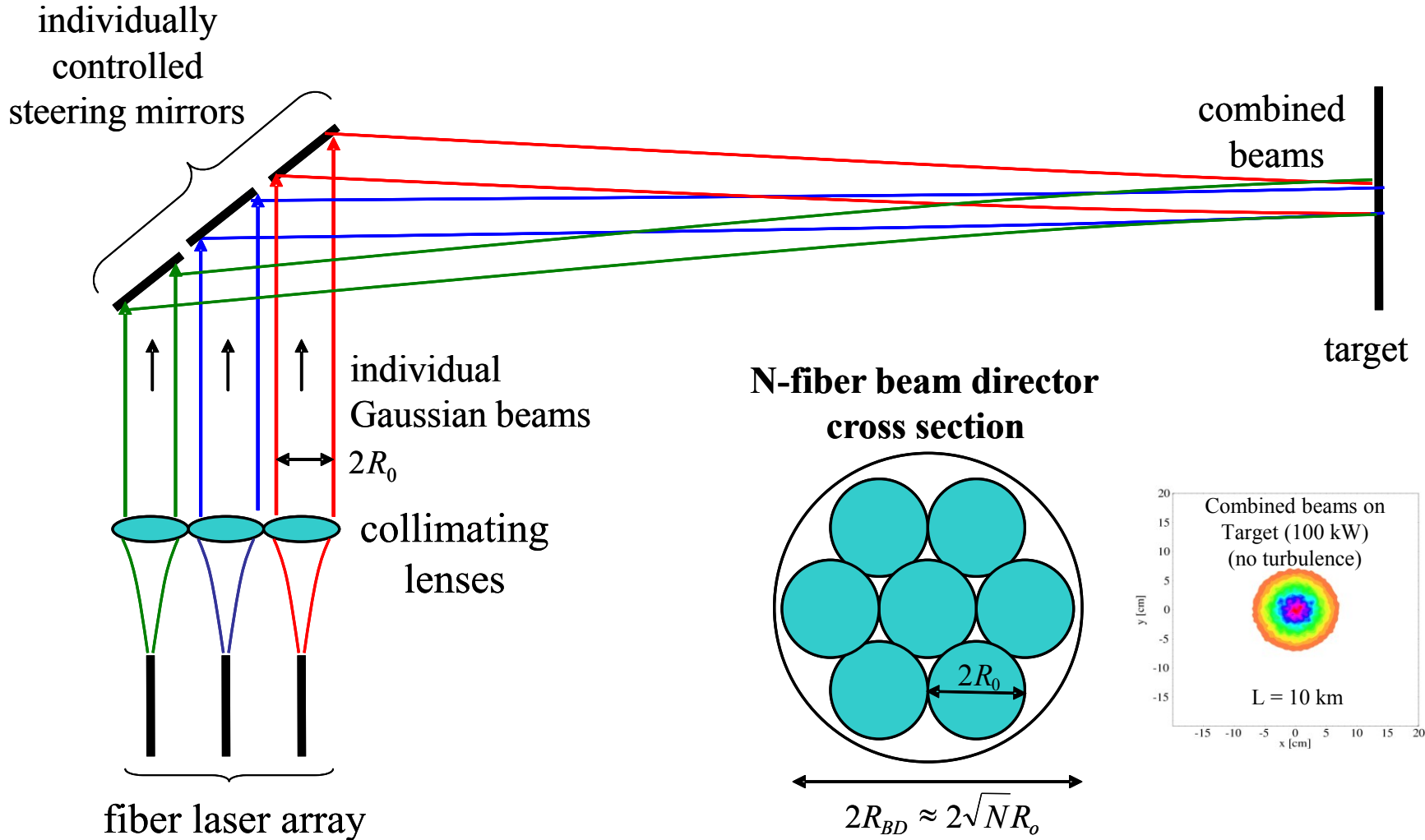
- High Wall – Plug Efficiency ( $> 30\%$ )

- High Optical Quality

# Fiber Laser

(1 kW, 1.6 kW, 1.6 kW and 2 kW)



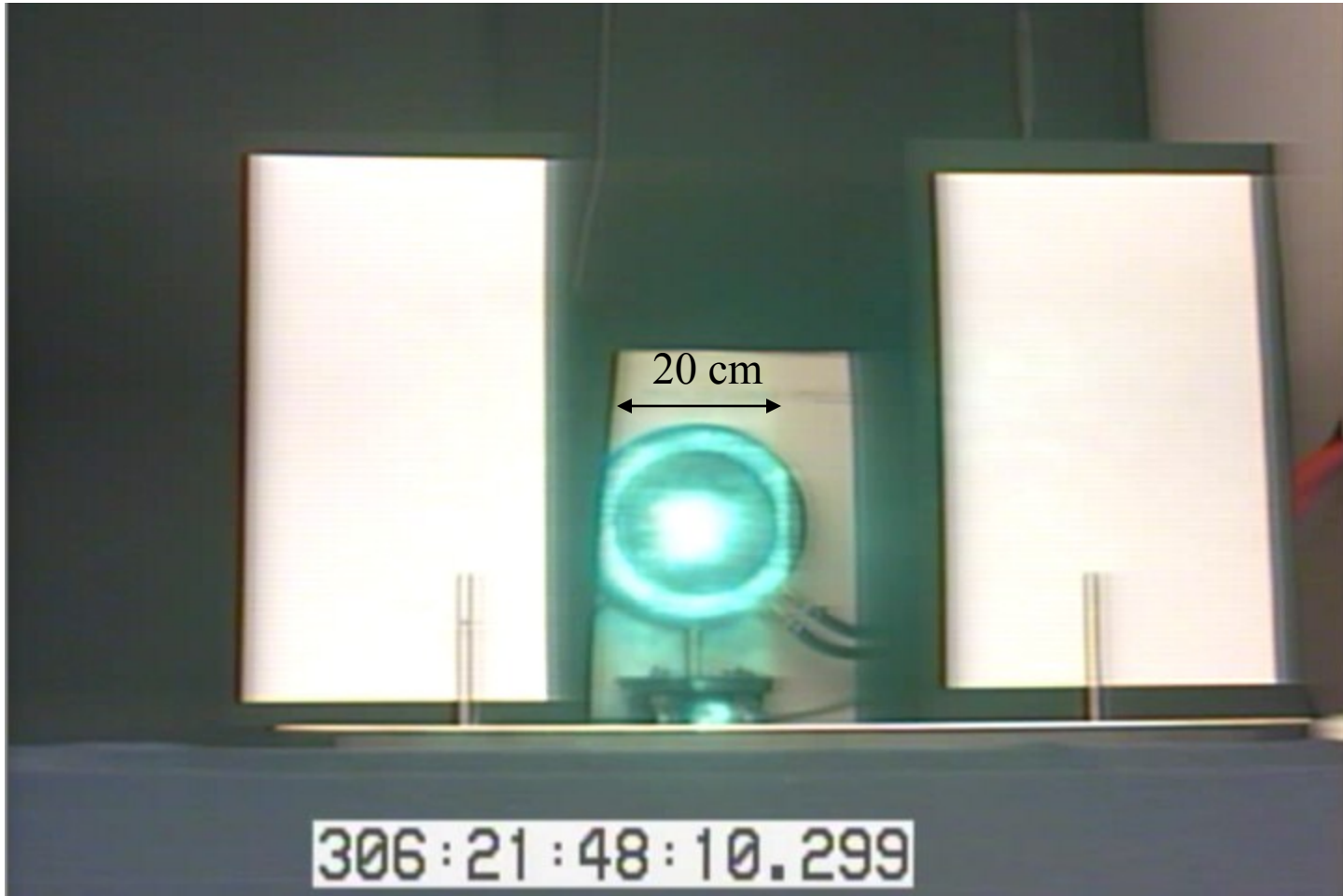


- **NRL Memorandum Report -6790-06-8963; also JDE 2, 273 (2007)**
- **U.S. Patent # 7,970,040 B1 (June, 2011)**
- **IEEE Journal of Quantum Electronics, 45, No. 2 (2009)**



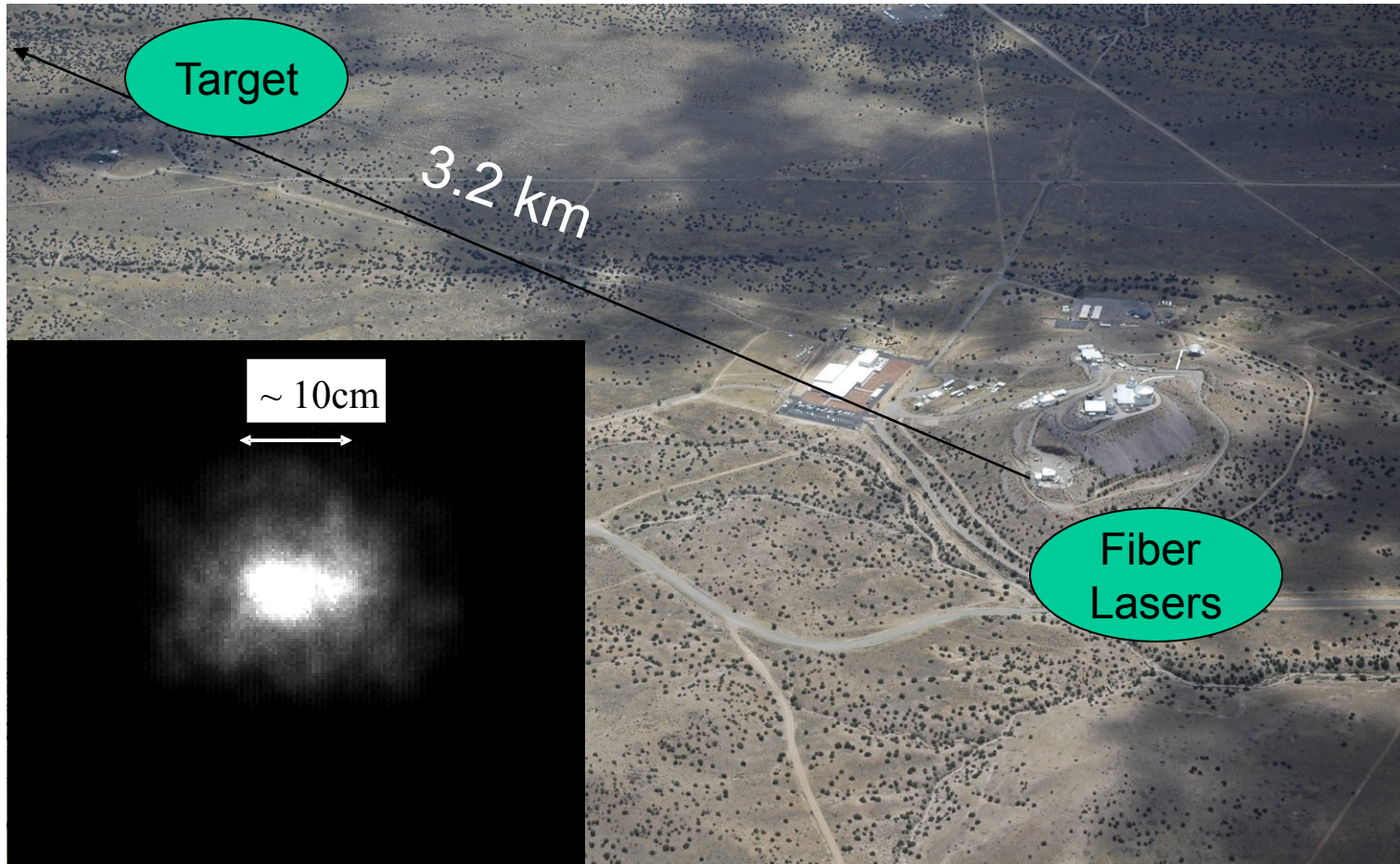
# Four Incoherently Combined Fiber Lasers (NRL), 1.2 km Range

3 kW transmitted, 2.8 kW on target , 11/02/07



# Starfire Optical Range (NRL) Propagation Range 3.2 km

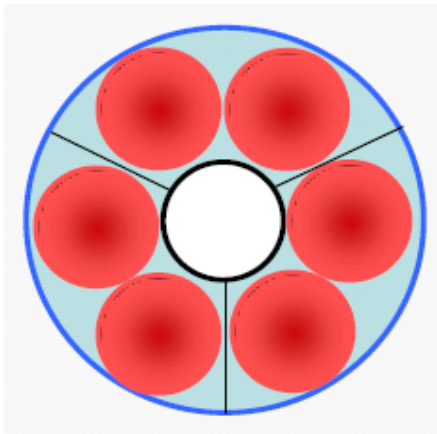
Incoherently combined fiber lasers,  $\sim 5$  kW, cw,  $M^2 \sim 1$



# Navy Laser Weapon System (LaWS)

- Based on the successful results of the NRL fiber laser program, the Laser Weapon System (LaWS) program (classified) was started in 2008 by NAVSEA, PMS 405

Power per fiber  $\sim 5$  kW



- Successfully tracked, engaged, and destroyed a UAV while in flight (May 24, 2010)



# 500 kW Fiber Laser Weapon System



- Laser power, CW:  $P = 500 \text{ kW}$
  - # of Fiber lasers :  $N = 63$  ( $P_{\text{fiber}} = 8 \text{ kW}$ , incoherently combined)
  - Wall – plug efficiency  $\sim 30 \%$
  - Beam director:  $R_{BD} = \sqrt{N} R_o \approx 50 \text{ cm}$
  - Volume of optics  $\approx 8 \text{ m}^3$
  - Weight of optics  $\approx 10,000 \text{ lbs.}$
  - Water cooling  $\sim 1,000 \text{ gallons/min.}$
- } excluding power supply and cooling





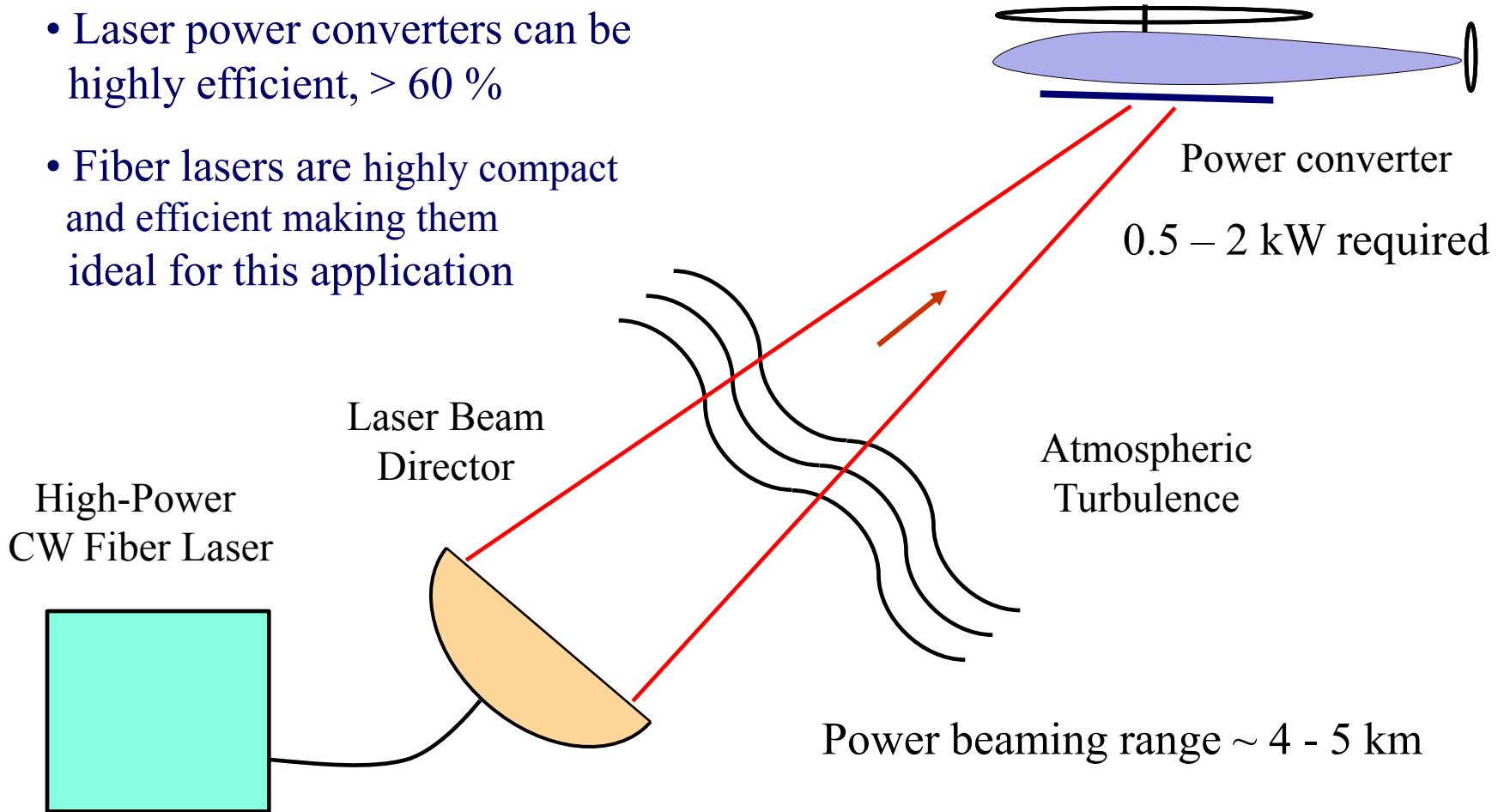
# Solid State Slab Laser

- Joint High Power Solid State Lasers (JHPSSL)
- Wavelength, 1.06  $\mu\text{m}$
- Power achieved 105 kW (2009) - Northrop Grumman
- Wall-plug efficiency, 20%
- Modular design
- Compact

# Laser Power Beaming

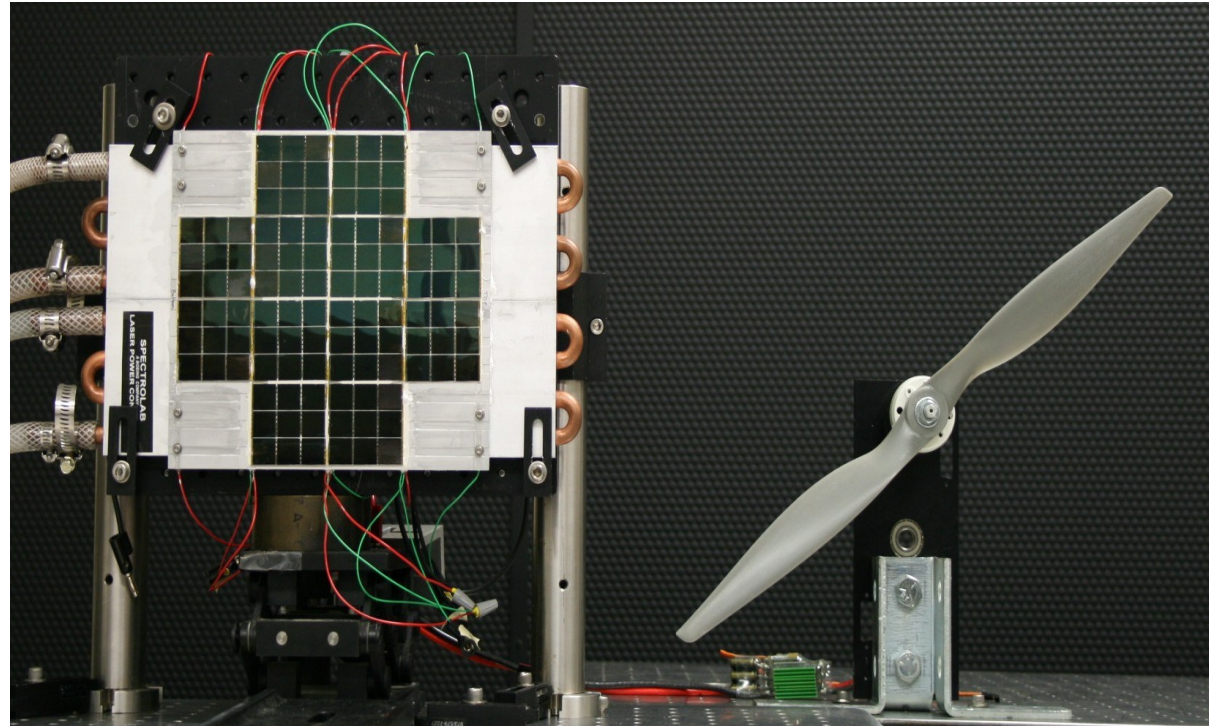
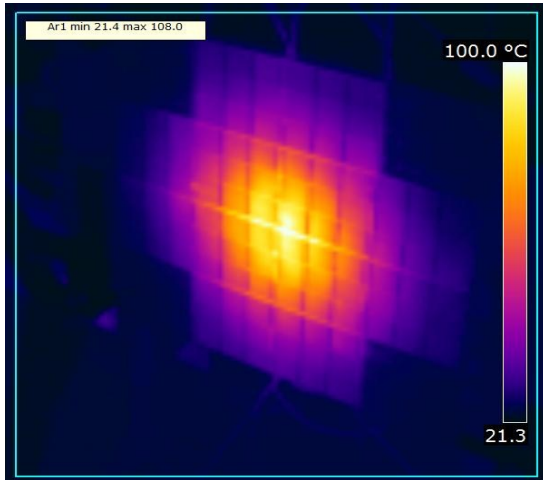
## New Operational Capabilities for the Navy/DoD

- Multiple kilowatts over multiple kilometers
- Laser power converters can be highly efficient, > 60 %
- Fiber lasers are highly compact and efficient making them ideal for this application



# Laboratory Demonstration of Laser Power Beaming using Fiber Lasers

## Semiconducting Convertor: InGaAs Spectrolab



- Efficiency ~ 42%
- 9 chips in series yields ~ 6 V, 8 A
- Total power  $\sim 12 \times 48 \text{ W} = 576 \text{ W}$



# Challenges

- Laser propagation in a maritime environment
  - turbulence
  - aerosols
  - thermal blooming
- Adaptive optics in deep turbulence
- Scalability to MW power levels
- Thermal management



# Back Up Slides