Physics, Materials, and Applied Mathematics Research

("PM&AM Research" http://www.physics-math.com)

Damage Rings and Momentum Transfer from UPL/Materials Interactions

Dr. Kevin Kremeyer

VP of Research

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Materials Interaction Projects ("Areas of interest.")

Target Interactions/Effects; Filaments; Energy-Propagation

Applications ("Why are they interesting?")

Micromachining; Space Propulsion; Directed Energy; Secondary Effects

Effects ("What is of interest?")

Ablation; Ionized Plumes; X-Rays; Electrons; Plasma; Impulse; Shockwave

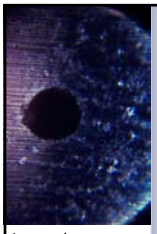
Diagnostics ("How is it being characterized?")

Spectrometers (IR→X-Ray); Surface Characterization (AFM, SEM, Imaging, White light Interferometry, Profilometry);
LANL-time-resolved measurements; Thrust Stand; Acoustic Sensors; Etc.

"Enhanced Lethality Using Self-Channeling Short-Pulse Lasers"
TM: Dr. Pete Latham-AFRL/Kirtland
Tune pulses to optimize damage/ablation of a given target; understand materials interactions, damage processes, and 2nd-ary effects → applications

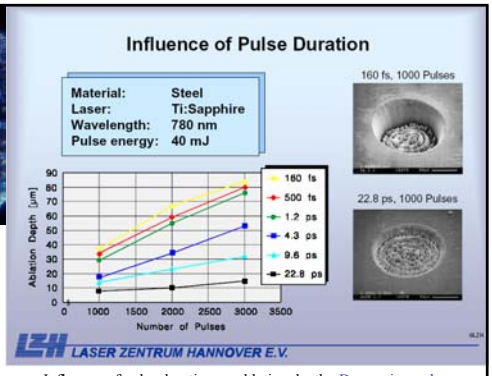
"High-I_{sp} Propulsion through Electromagnetically-Confined Laser Ablation"
TMs: Dr. Jean-Luc Cambier, Dr. Andrew Ketsdever, Dr. Marcus Carroll AFRL/Edwards
Measure/Verify the Impulse/Thrust Imparted by Ultrashort Pulse Laser Ablation

Propagation and Space Applications

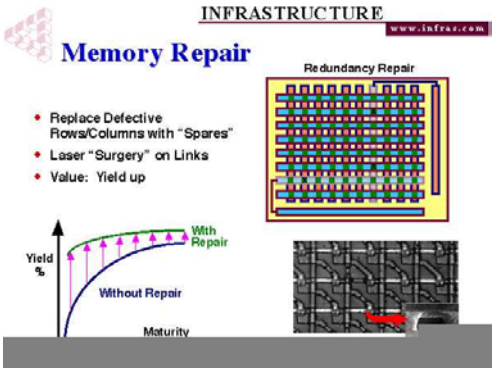


1ps excimer
248nm;<100mJ
Nickel-based
Alloys:

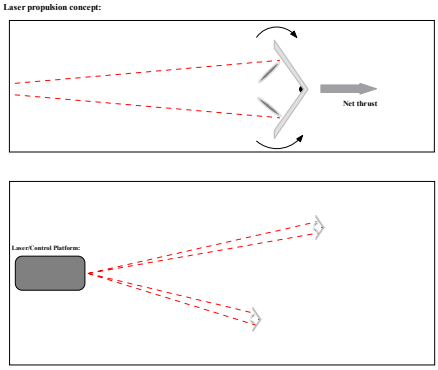
- Inconel 600
- Hast-X
- Inconel 625



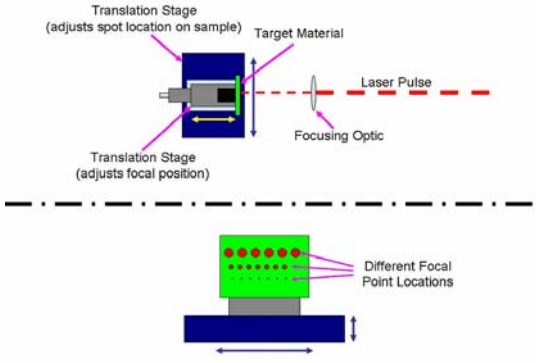
Influence of pulse duration on ablation depth: Decreasing pulse width → More efficient ablation
(less time for shielding mechanism to evolve)



One application: "mother ship" controlling "baby ships"



Experimental Geometry

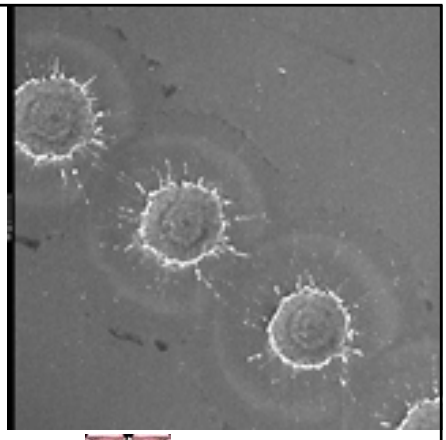


SEM image of Aluminum

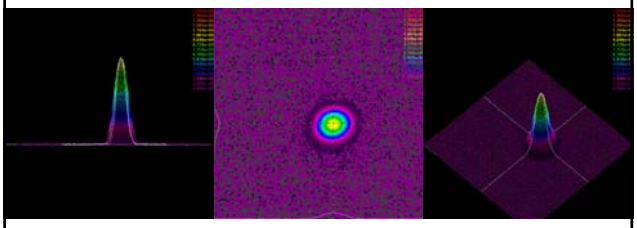
Interesting Ring Structure

What causes it?

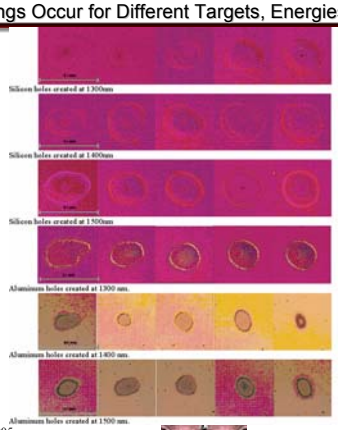
-Many Theories



Beam Profile – nice and continuous…effectively Gaussian



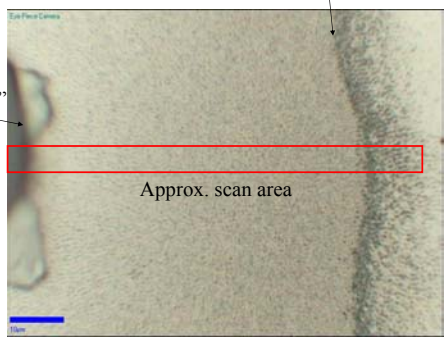
Damage Rings Occur for Different Targets, Energies, Wavelengths, Etc



Chemical Change?
→Raman Spectroscopic Imaging

Outer "ring"

Inner "ring"



Raman spectrum of silicon

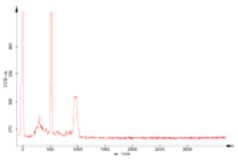


Image created using 520 cm-1 Raman peak of silicon

Silicate glass spectrum – note Broad feature around 300 cm-1. This is not a definitive spectrum, but the broad peak is typical of silicate glasses

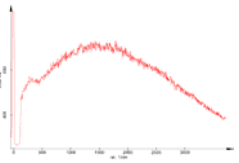
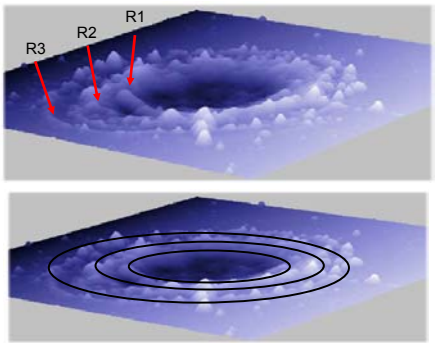
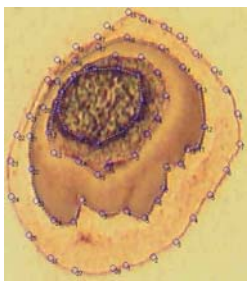


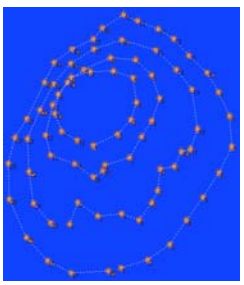
Image created from ~300 cm-1 glass band

AFM Images Show Ring Structure

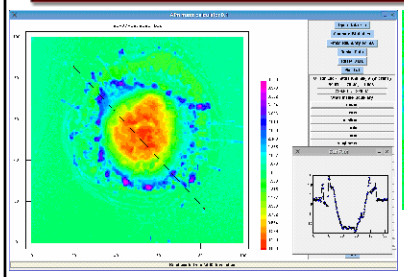


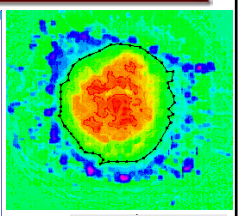
Ring Characterization-Software Development





Software Screenshots



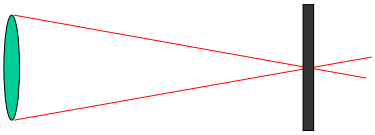


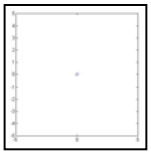
Stats inside Boundary	
mean	-0.93
rms	0.47
median	-1.04
min	-1.75
max	0.55
roughness	0.41
skew	0.43
area	1198.78
volume	-1116.72

Quantify **roughness**, **radii**, **area**, and **volume** removed/added in different regions (including **multiply connected** domains)
Also: Statistics

Target Location

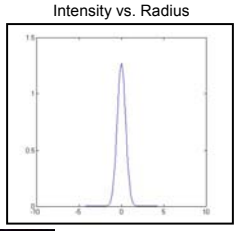
Beam Size





Intensity vs. Radius

Beam Intensity Profile



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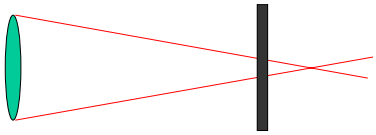
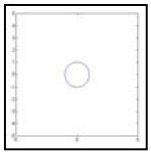
Beam Size





Intensity vs. Radius

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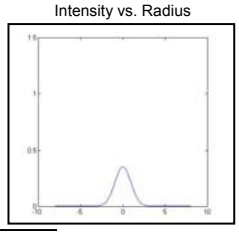
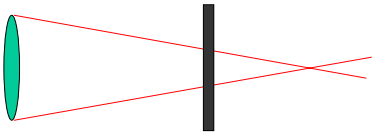
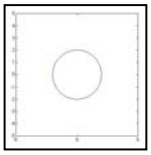


Target Location

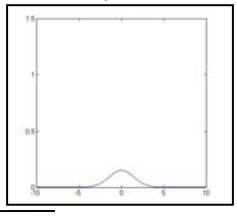
Beam Size





Intensity vs. Radius

Beam Intensity Profile



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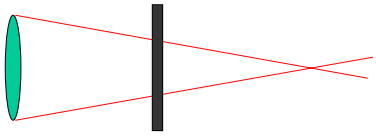
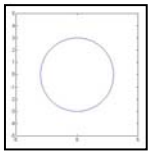
Beam Size





Intensity vs. Radius

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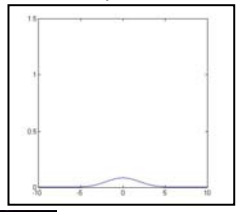
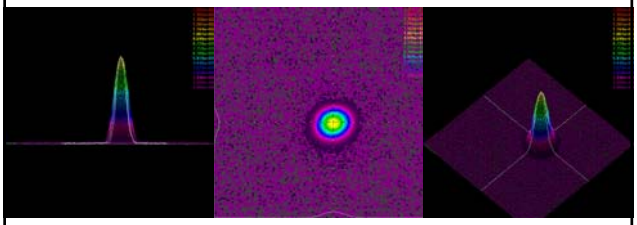


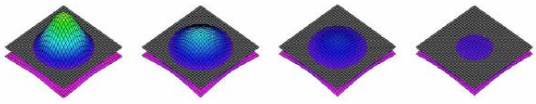
Beam Profile Revisited:

Coarse-graining the color map suggests nature of rings.

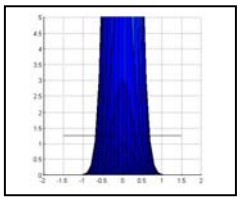
Different physical phenomena/interactions for different intensity ranges?

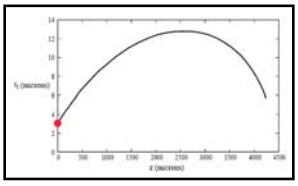


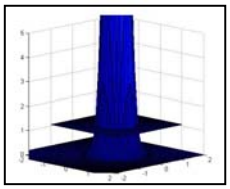
Intensity Thresholds

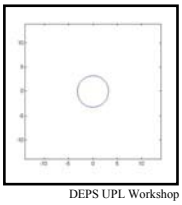


2nd Ring Analysis









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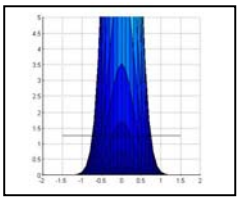

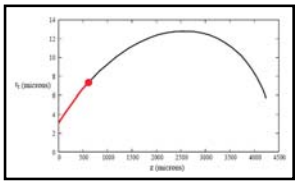

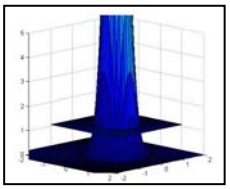

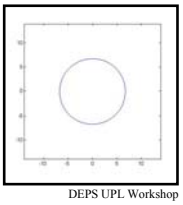

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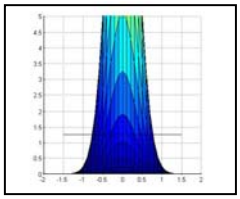

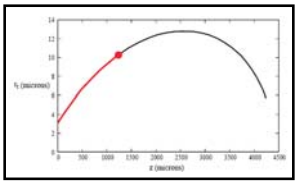

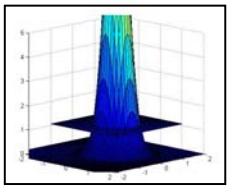

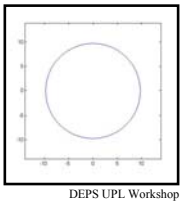

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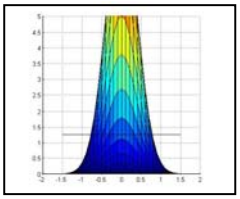

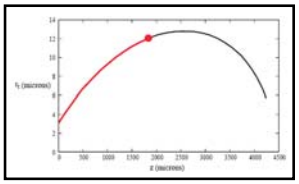

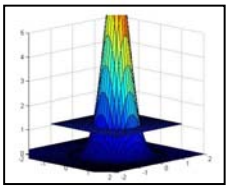

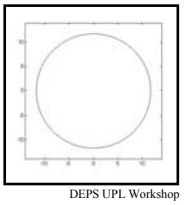

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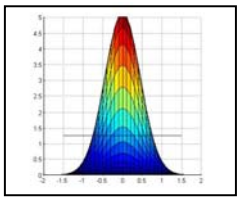
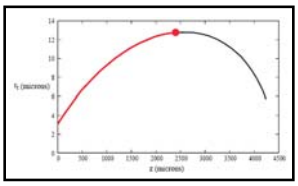
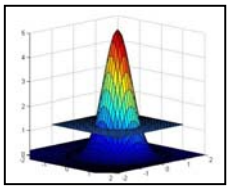
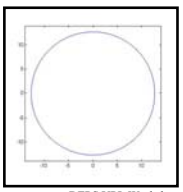
2nd Ring Analysis









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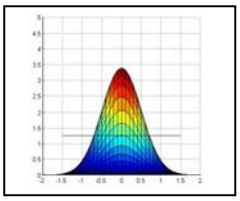

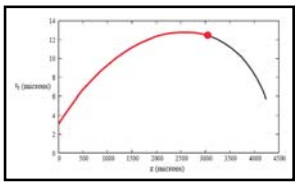

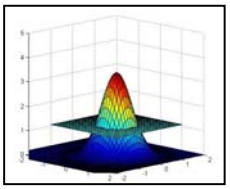

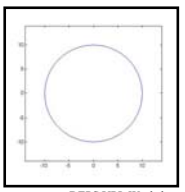

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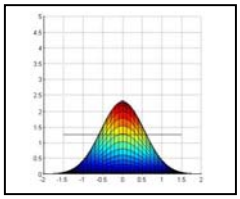
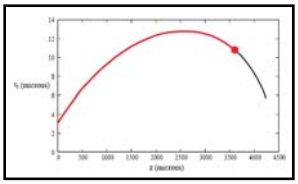
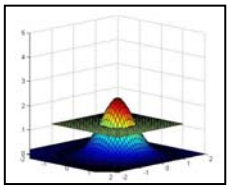
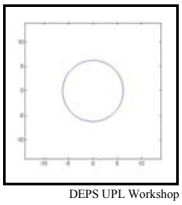
2nd Ring Analysis

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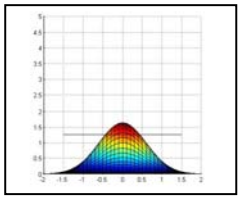
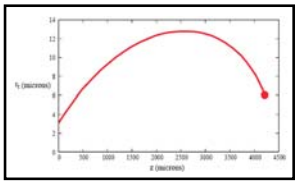
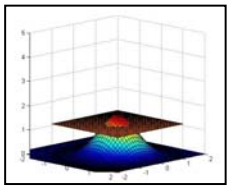
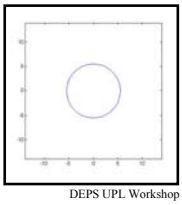

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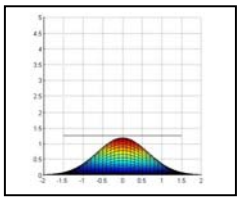
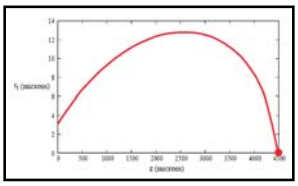
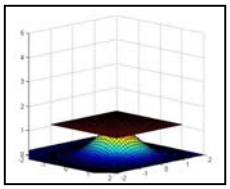
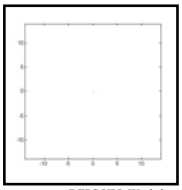

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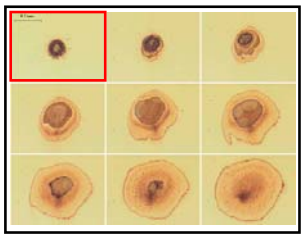
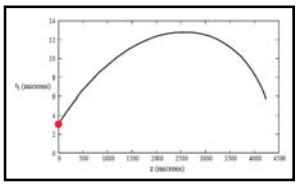
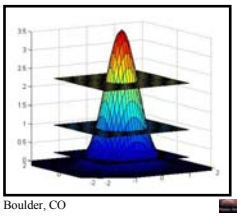
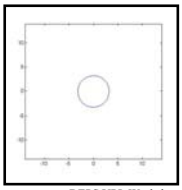

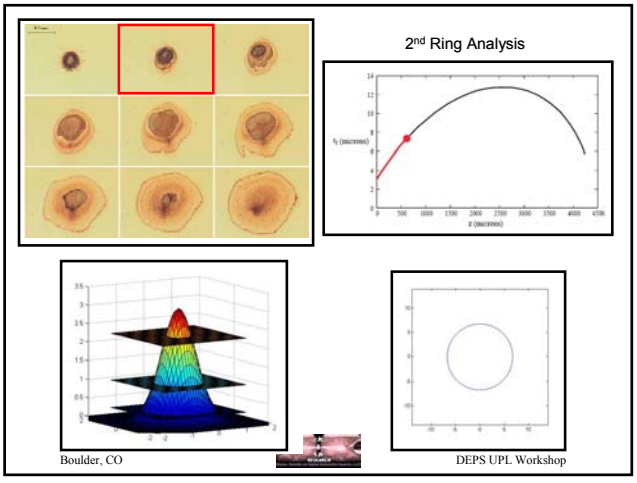
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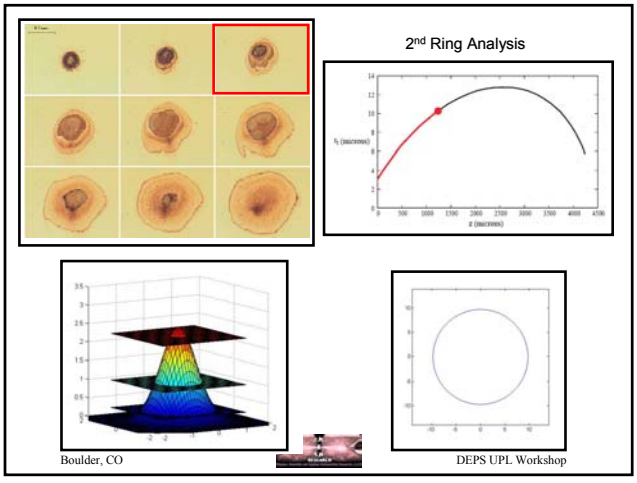
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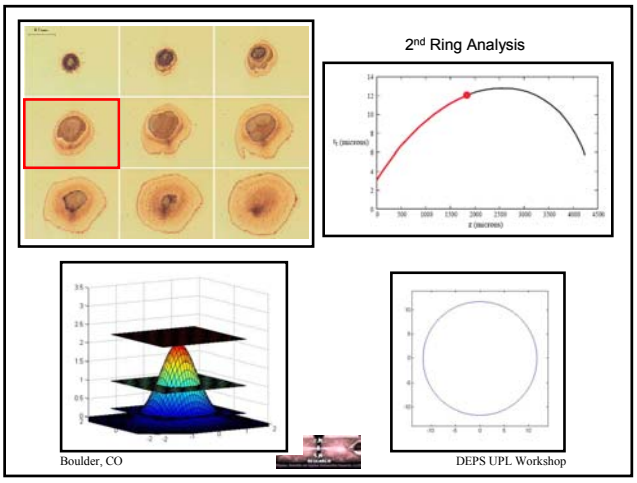
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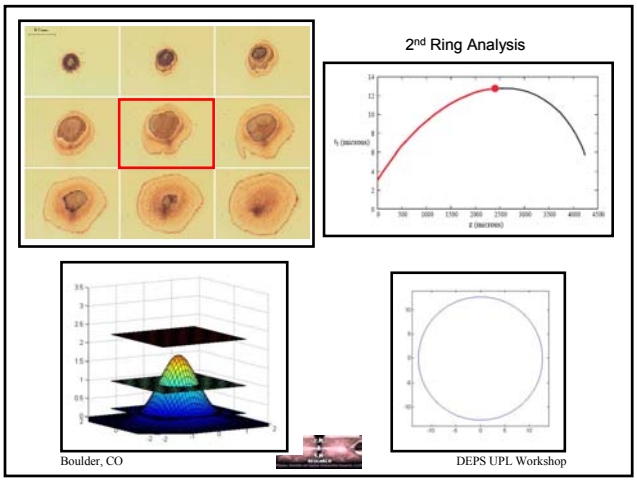
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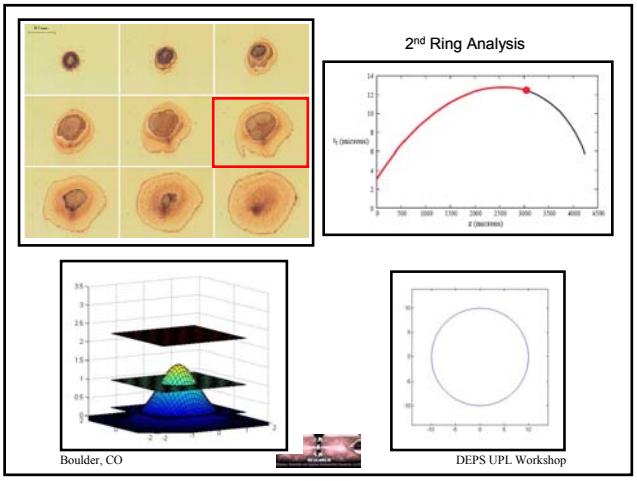
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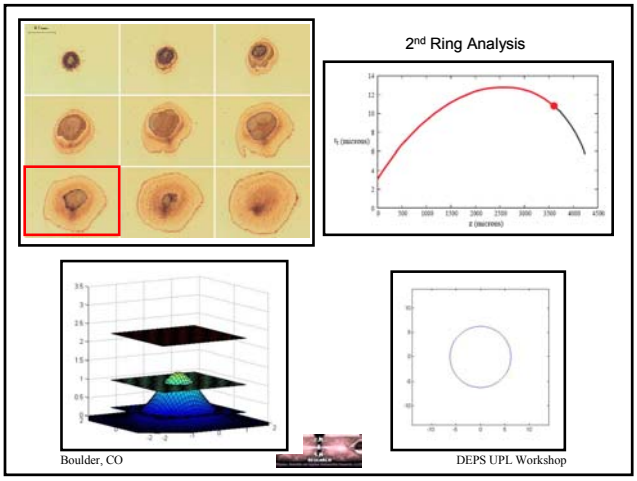
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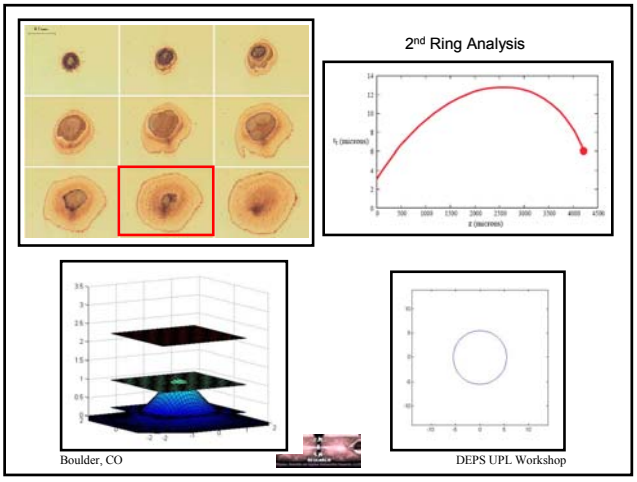
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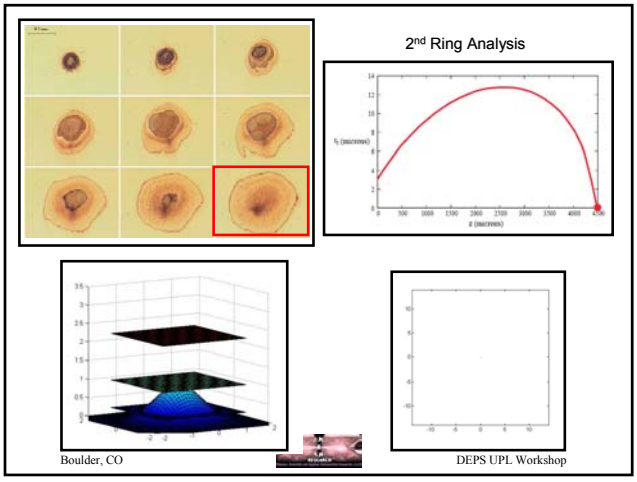
2nd Ring Analysis
Boulder, CO
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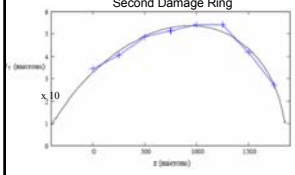
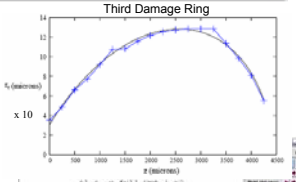
Plots of damage ring radius vs. displacement from lens using an aluminum sample.

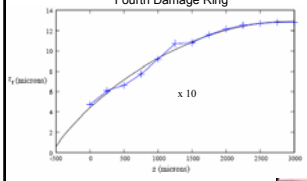
Second Damage Ring

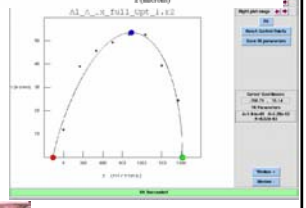


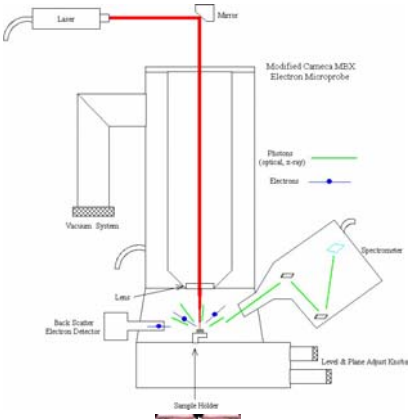
Third Damage Ring



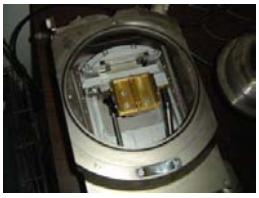
Fourth Damage Ring







X-Ray/electron spectrometers and sample stage-all in vacuum.

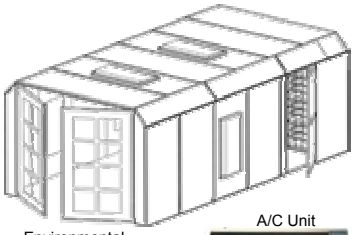


Cameca MBX

X-ray: sub-kV – 40kV (max)
Secondary electrons
Immediate analysis
Drive interaction w/E-field

Building additional chambers
to drive ionized interaction regions
with varying fields and frequencies.

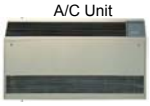
Environmental Housing: RF/Dust/Temperature/Humidity/Power



Environmental Housing

UPS

HEPA Filter

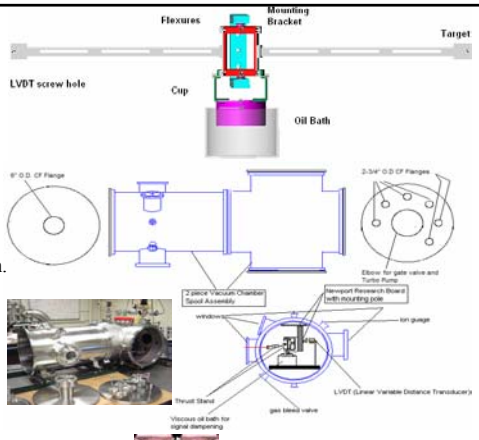


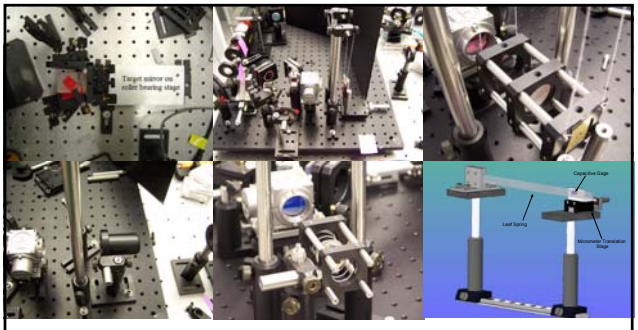
A/C Unit

Environmental Housing: waiting for laser to drive OPA

- **Reliable**
- **Well-tested**
- **Developed under EAFB funding.**

Still prefer a lighter, more compact system. Will continue developing this. Fit in carry-on luggage?



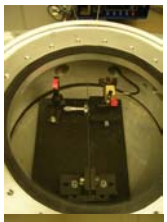


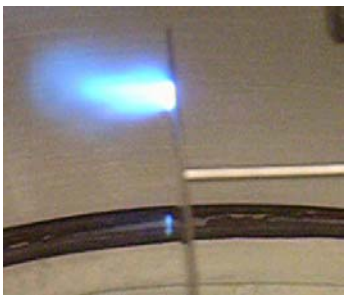
Interferometric measurement geometries of a: roller bearing stage (top left); 2-point pendulum (top center); 4-point pendulum (top right); O-ring system (bottom left); double spring system (bottom center); and a leaf spring schematic w/a capacitive guage (bottom right).

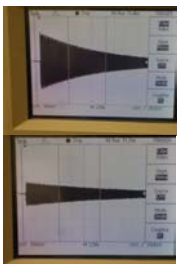
Evaluated numerous metrology methods:

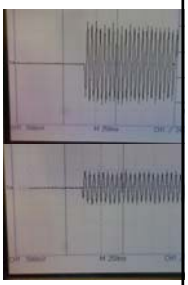
- Interferometric
- Capacitive
- Magnetic
- Machine vision
- Fiber-optic
- Laser
- Etc

All were benchmarked against a high-precision interferometer (<10nm), for which we developed very stable deconvolution algorithms and software.

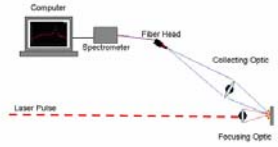


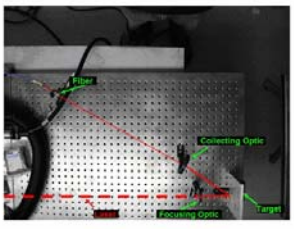




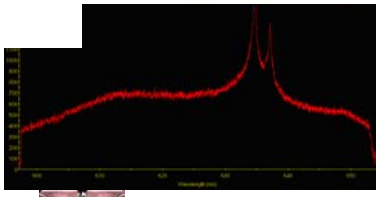


Displacement of the leaf spring when subjected to a ~300 mJ laser shot in air (top left) and under 3 Torr (bottom left). Also shown is the displacement of the leaf spring when subjected to a ~150 mJ laser shot in air (top center) and under 3 Torr (bottom center… note the expanded vertical scale). Thrust data from the 300 mJ laser in air and under 3 Torr (top and bottom right, respectively), zoomed in to see the initial point of impact. (The 150mJ runs are not compared because of their different scales).





Also investigating spectral broadening as a plume diagnostic (of temperature or possibly of velocity).



Conclusions:

•Many applications and much interest in UPL/Matter Interactions.

•Solid progress on ablation characterization and X-ray diagnostics.

•Measuring and analyzing imparted impulse and target damage.

•Building/developing the capabilities to measure the secondary target effects and resulting effectiveness-enhancement of the full slate of propagation applications currently under consideration.

•Fortunate one-shot assessment of a range of laser intensities.

•Promising space applications.

This work was supported in part under AFRL contracts
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