RA4-FA2: Direct Laser Impulse

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MSEE | MATERIALS SCIENCE IN EXTREME ENVIRONMENTS UNIVERSITY RESEARCH ALLIANCE

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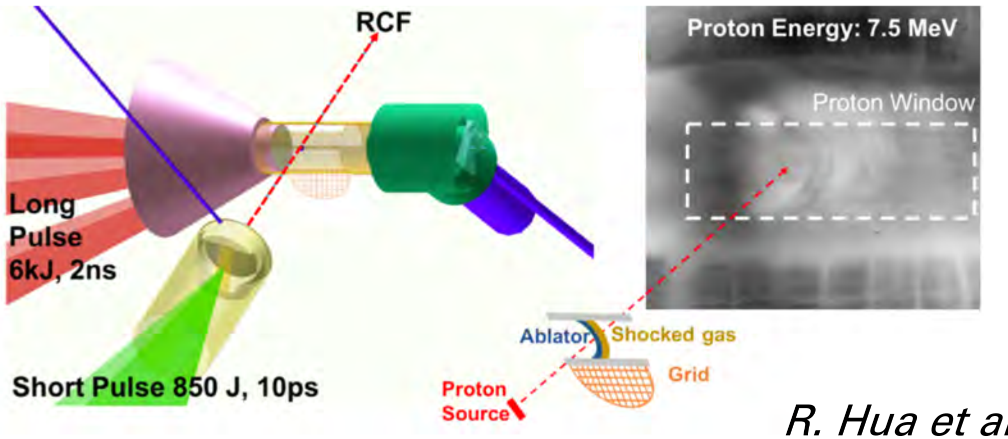
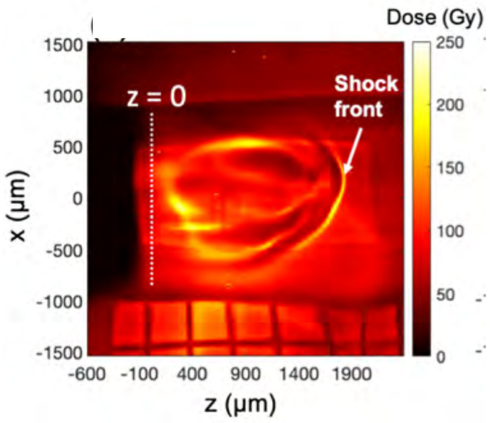
Problem and Challenges

- Main goal is to understand and optimize the ability of high-power lasers to simulate X-ray blow-off and thermo-mechanical shock.

- Major challenges include:
  - How can we improve laser energy coupling to the target to generate strong and smooth shocks?
  - How can we scale or simulate x-ray blow-off and TMS in the laboratory testbed?
  - How does the shock propagate across boundaries?





R. Hua et al., Physical Review Letters **123**, 215001 (2019).

Scientific Drivers

SCIENTIFIC DRIVERS:

- Predict & understand the interaction of high intensity x-ray fluxes with near-surface materials
- Develop use of high-power lasers and tamper materials to simulate x-ray blow-off and thermomechanical shock

Thrust 1: X-RAY INDUCED BLOW-OFF

HIGH INTENSITY X-RAYS INTERACTION
Material ablation; black body radiation; power density; solar cells

TRANSPORT
Layer targets; warm dense matter; conductivity

PARTICLE GENERATION
Electrons; photons; equation of state

Thrust 2: DIRECT LASER IMPULSE

LASER PLASMA INTERACTION
Phase plates; laser spot sizes; energy absorption; shock generation

TAMPER MATERIALS
Optically designed films; shock energy deposition

NUCLEAR EFFECTS
Damage; shock propagation across boundaries; material damage

Thrust 3: DIAGNOSTICS AND PREDICTIVE MODELING

DIAGNOSTICS
Spectroscopy; imaging; Velocity Interferometer System for Any Reflector (VISAR)

MODELING
Prediction of laser and x-ray irradiation; synthetic diagnostics

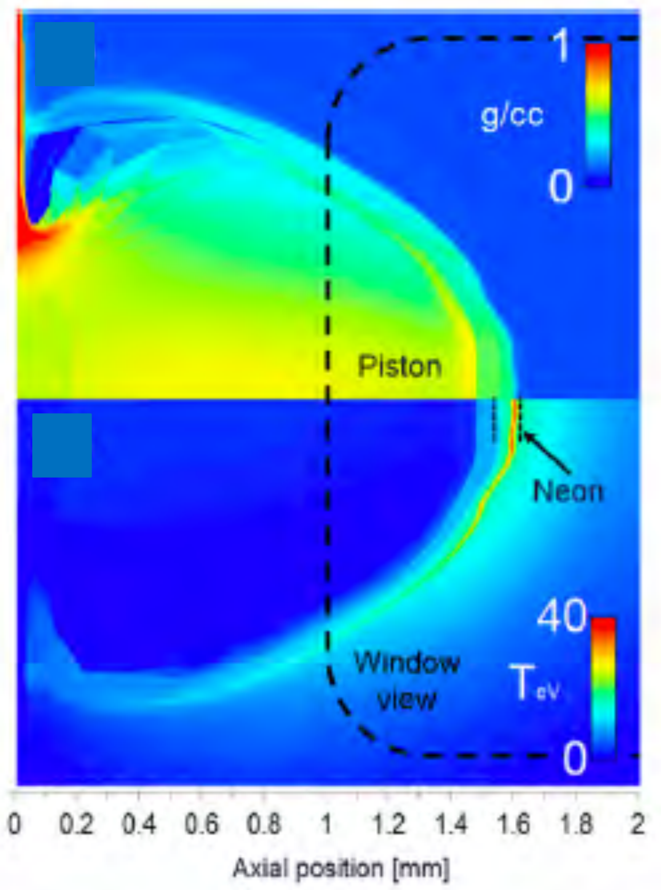
← OPTICAL AND X-RAY IRRADIATION →

Personnel

Investigators and Collaborators	Position	Institution	Workforce
Farhat Beg	**FA Coord**	**UCSD**	**1 PhD; 0.5 PD**
Javier Garay	PI	UCSD	1 PhD
Hari Harilal	PI	PNNL	0.25 PD
Harry Radousky	PI	LLNL	Co-advisor to UCSD students
Sean Regan	PI	Rochester	0.5 PhD
Rick Spielman	PI	Rochester	1 PhD; 1 PD
Cliff Thomas	PI	Rochester	0.5 PhD
Mark Foster	Collaborator	JHU	
Gena Miloshevsky	Collaborator	VCU	
Jacob Calkins	Collaborator	DTRA	

Long-term Goals and Strategies

- Understand and optimize the ability of high-power lasers to simulate X-ray blow-off and thermo-mechanical shock
  - generation of uniform shocks by employing phase plates and large overlapping laser spots (~cm^2)
  - improvement in laser-energy deposition to generate stronger shock waves using modeling tools and tailoring the properties of tamper materials
  - investigation of shock propagation in tamper materials
  - development of state-of-the-art diagnostic tools to measure laser-deposition, plasma characterization and transient impulse into the target.

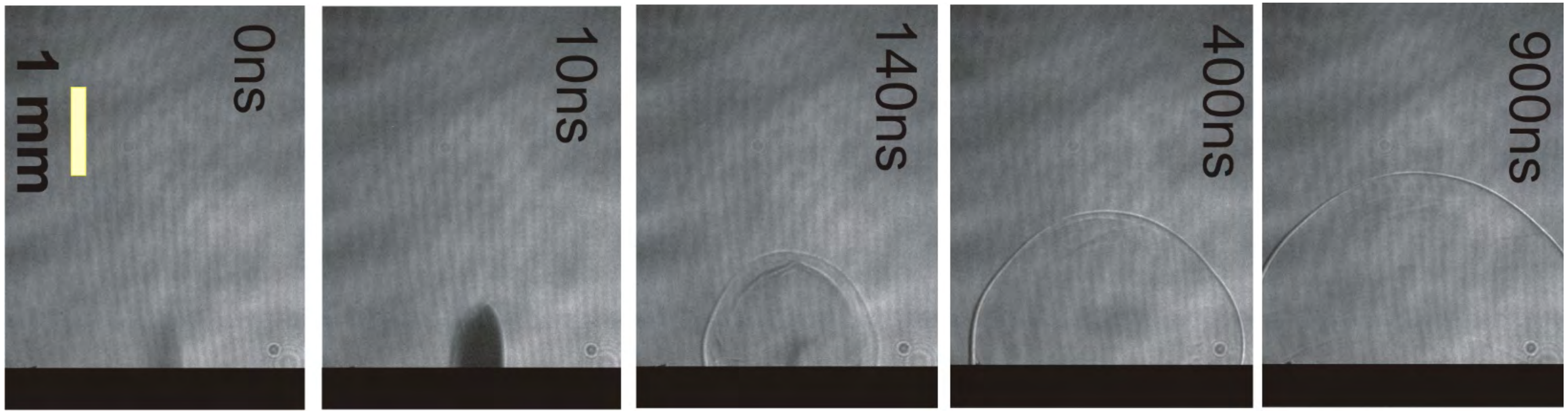


T. Clayson et al. / High Energy Density Physics 23 (2017) 60–72

IPP Goals

- Investigate the major factors influencing the efficient coupling of the laser energy to the target for the strong shock generation as a function of
  - laser pulse length,
  - wavelengths, and
  - spatial profiles
- Carry out radiation hydrodynamics simulations to guide experiments, which will facilitate validation of the experimental data.

Shock wave propagation



IPP Strategies

- Thorough understanding of the laser energy coupling and shock strength as a function of wavelength, fluence, pulse length and spatial profile
  - correlate plume fundamentals and shock dynamics
  - shock propagation in tamped targets
  - impulse of tamped experiment with realistic objects

- Bi-weekly meetings to discuss progress.

What is Revolutionary and/or Unique About this Research?

- Thermo-mechanical shock (TMS) is a major threat for exo-atmospheric objects.

- TMS becomes a major vulnerability issue at high X-ray intensities and with the appropriate X-ray spectrum.

- Utilize lasers with a range of energies to conduct a variety of direct laser impulse experiments
  - high laser flux (energy) to directly measure the TMS at multi-Mbar levels
  - measure shock and particle velocities
  - develop Hugoniot plots.

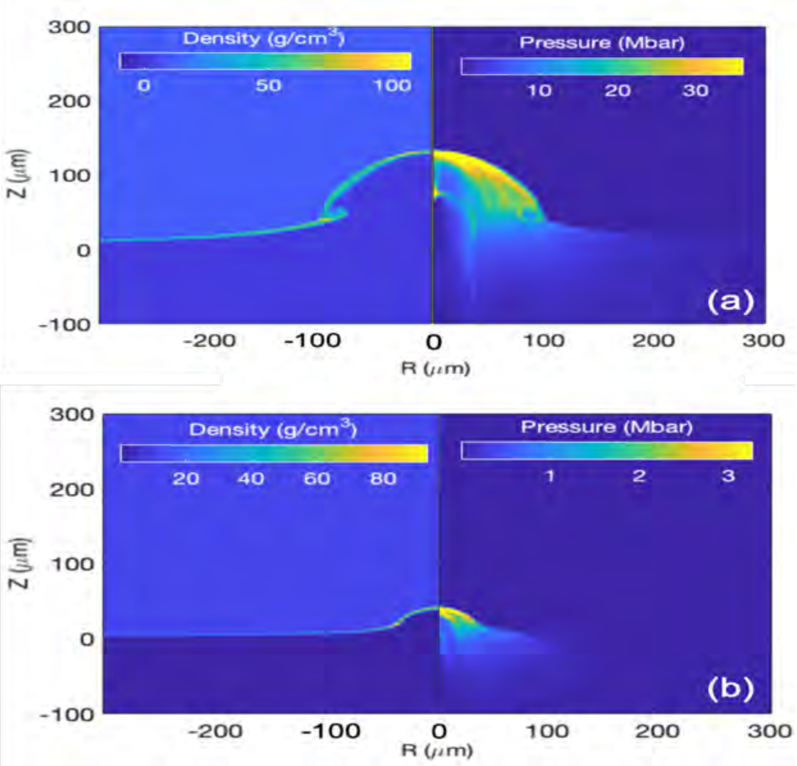
Description of activities at UC San Diego (Beg)

- **Beg** and his students will initially participate in the analysis of the data taken by collaborators at LLNL.

- Data analysis will guide future experimental plans.

- They will carry out experiments to study plasma plumes and shocks with lasers ≤100 J.

- They will participate in radiation hydrodynamic simulation to prepare experiments on the Omega laser system in collaboration with RA-4 team.

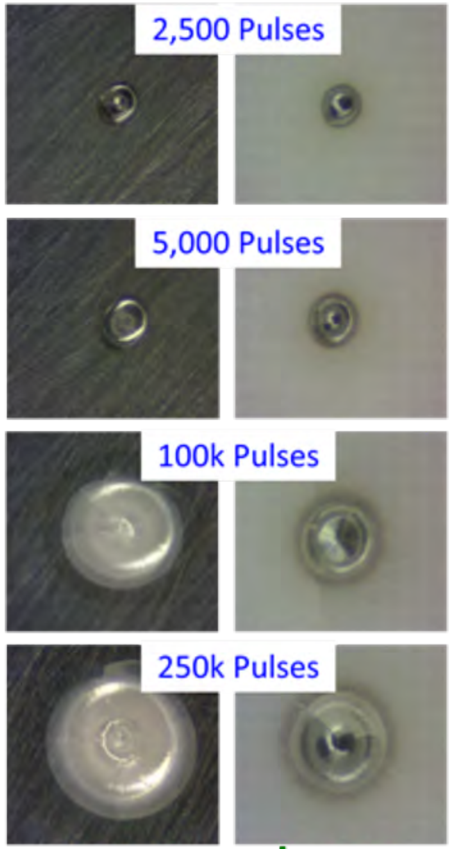


Description of activities at UC San Diego (Garay)

- **Garay** and his students will prepare and test the targets for experiments.

- They will design targets to increase coupling of the laser energy into the targets
  - use powder densification to produce bulk (large-sized targets)
  - characterize targets using X-ray diffraction techniques
  - measure material properties such as thermal conductivity and modulus
  - design tamper targets.

- They will coordinate their efforts with experimental teams.



High Low
intrinsic defects

Description of activities at Laboratory for Laser Energetics (Spielman, Regan and Thomas)

- **Spielman, Regan, and Thomas** and their students will start the process of using Omega laser to generate large-area (~cm^2), uniform laser illumination on samples. UR/LLE will work with UCSD to develop the targets.
  - Training of students and young post-docs is a key part of the effort

- They will initially use LLE DRACO (2-D MHD) to explore the generation & expansion of ablated material as well as shocks in the target.
  - Use DRACO to study the effect of laser wavelength and laser pulse width.
  - Use DRACO to predict the impact of tampers.

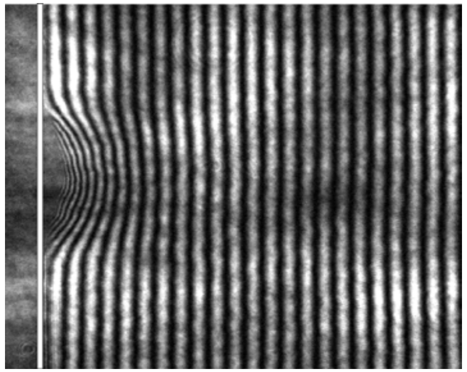
- They will collaborate with the RA-4 Team on the needed diagnostics.

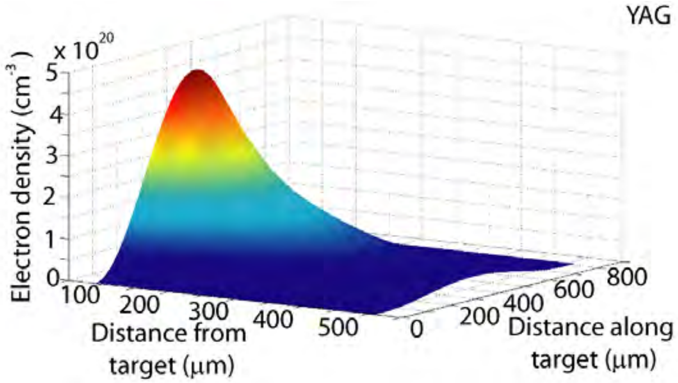
Description of activities at Lawrence Livermore National Laboratory (Radousky)

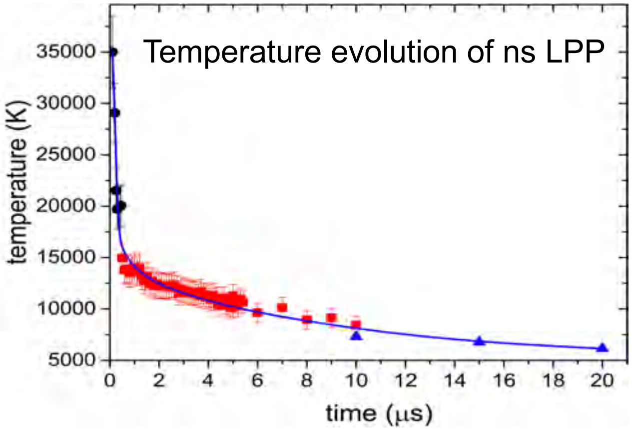
- **Radousky, LLNL mentors** and their respective Ph.D. students and Post-Docs will be involved in the major tasks, which include:
  - studying laser-matter interactions using ns and ps lasers at high fluences to generate uniform shocks
  - improving laser-energy deposition to generate stronger shock waves by tailoring properties of tamper materials;
  - modeling laser matter interactions to guide tamper material development
  - developing diagnostic tools to measure laser-deposition, and transient impulse into the target.
- LLNL team has the experimental/modeling capabilities needed to participate in these tasks and will use low-energy lasers ($\leq$10 J) to simulate thermo-mechanical Shock (TMS) events and explore the underlying physics. These lasers are available in-house.

Description of activities at PNNL (Harilal)

- **Harilal** will mentor visiting students and postdocs
- Diagnosis of laser-produced plasma with high time and space precision
  - an array of diagnostic tools will be used for collecting LPP information (temperature, density, kinetics of particles (atoms and ions), shock velocity, plume morphology, mass ejecta)
  - diagnostic methods include fast gated imaging, focused shadowgraphy, interferometry, emission spectroscopy, Faraday cup
  - state-of-the-art diagnostic tools will be developed for evaluating shocks (VISAR, Ultrafast laser-based absorption methods)







Plans for Collaborative Exchanges

- **Close collaboration** between participating institutes on precise diagnoses of
  - transient plasma plumes,
  - energy coupling,
  - induced shockwaves with high spatial and temporal precision
  - simulation of direct laser impulse

- **Sharing** of diagnostics and modeling tools
  - optical emission spectroscopy,
  - filtered and spectrally integrated fast-gated imaging,
  - shadowgraphy, and interferometry
  - VISAR
  - radiation hydrodynamics codes

Collaborative Exchanges w/CCRI

- Use of diagnostic tools such as VISAR, Streaked Optical Pyrometer, and fiber optic sensors will be shared.

- Coordinate use of frequency domain interferometry by employing ultrafast lasers (fs laser pulses).

- Explore spectroscopic tools such as ultrafast laser-based absorption methods for interrogating the shocked transparent materials which can provide molecular-level chemical information in the shocked region.

- Design and test of Fiber-optic line (1D) VISAR architecture that leverages spectral encoding of the spatial information on ultrafast laser pulses.

Summary

- Investigate the major factors influencing the efficient coupling of the laser energy to the target for the strong shock generation as a function of
  - laser pulse length,
  - wavelengths, and
  - spatial profiles
- Thorough understanding of
  - plume fundamentals and shock dynamics
  - shock propagation in tamped targets
  - shock of surrogate material over the range of laser energies