Center for Laser Experimental Astrophysical Research

Project Director: Carolyn C. Kuranz
University of Michigan

A report on work funded by the Stockpile Stewardship Academic Alliances and HEDLP joint program and by the National Laser User Facility through grant numbers DE-FG52-09NA29548 and DE-FG03–00SF22021

The Center also has or has had support from LLE, LLNL, DTRA, LANL, NRL, and ASC
The Center for Laser Experimental Astrophysics Research studies high-energy-density phenomena that are relevant to astrophysics

- We advance fundamental understanding of HED dynamics relevant to astrophysics
  - Radiation hydrodynamics
  - Complex HED hydrodynamics
  - Magnetized flowing plasma
- While advancing the required infrastructure
  - Computer simulation
  - Target fabrication
  - X-ray diagnostics
- The ultimate goal of these activities is to train junior scientists

X-ray radiography of a RT experiment at the National Ignition Facility with high energy fluxes
CLEAR team is oriented toward training students

- **Post Docs:** Handy, Gray, Young
- **Recent Grad students:**
  - Young (UM), Wan (LANL), MacDonald (UCB), Fein (SNL)
- **Current Grad Students (10)**
  - Rasmus (LANL), Davis, Belancourt, Elgin, Levesque, VanDervort, Angulo, Lefevre, Coffing, Melean
  - Many undergrads (10 – 15)
- **We graduate about 1 – 2 students/year**
- **We have an excellent publication record!**
  - > 100 since 2009
  - ~12/year
All of these students have been involved in experiments at Omega

This is a state of the art (not “aged”!) facility conducting world class, high-impact research in the national interest

It is critical that this facility be supported!
Our graduates have proven attractive to NNSA labs

• Most of our students come through the UM Applied Physics Program
  – Outstanding applicants; highly competitive
  – Diverse program – 30% women, 30% URM
  – Imes-Moore Fellowship (1st generation citizen, 1st generation college, financial hardship)

• Since 2007 we have graduated 13 PhDs from CLEAR and its predecessors
  – 7 went into the NNSA labs (2 LLNL, 3 LANL, 2 SNL)
  – 2 went into HEDP at SLAC and General Atomics
  – 3 remain in HEDP in universities
  – 2 went into industry

Harding, SNL
Di Stefano, LANL
Huntington, LLNL
CLEAR relies on experienced senior scientists with a breadth of experience

• Faculty:
  – Kuranz, Drake, Keiter, Van der Holst

• Staff:
  – Trantham, Klein, Gillespie

• Additional Faculty at UM:
  – Johnsen (ME), McBride (NERS), Willingale (EECS), Thomas (NERS)
Student spotlight: Dr. Willow Wan

- US citizen
- BS 2010, Physics and English, Montclair State University
- PhD 2017, CLASP
  - “Supersonic, single-mode and dual-mode Kelvin-Helmholtz instability experiments driven by a laser-produced shockwave”
- Multiple “Best Poster” Awards
- National Ignition Facility and Photon Science Award
- Currently a Postdoctoral Fellow at LANL
We value our scientific collaborators

Partial List

Negev/Israel – Malamud, Elbaz, others
Rice – Hartigan
Florida State – Plewa
Soreq/Israel – Frankel, others
LLE/Rochester – Froula, Theobald, Frank, Blackman, others
LLNL – Huntington, Park, Smalyuk, Moody, Remington, others
LANL – Flippo, Doss, Kline, Montgomery, Di Stefano, others
France – Koenig, Bouquet, Michaut, Loupias, Falize, Casner, others
Britain – Lebedev, Gregori, others
SLAC – Glenzer, Fiuza, (Hae-Ja) Lee
We experiment and collaborate at many HEDP facilities

<table>
<thead>
<tr>
<th>Led by CLEAR:</th>
<th>Facility</th>
<th>Collaborative participation</th>
<th>Facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation Hydro*</td>
<td>Omega</td>
<td>XRTS</td>
<td>Omega</td>
</tr>
<tr>
<td>Complex Hydro*</td>
<td>Omega/NIF</td>
<td>LLNL Complex Hydro</td>
<td>Omega &amp; NIF</td>
</tr>
<tr>
<td>Magnetized Flows*</td>
<td>Omega/JLF</td>
<td>LANL Complex Hydro*</td>
<td>Omega</td>
</tr>
<tr>
<td>Astrophysical Dust</td>
<td>Jupiter</td>
<td>Complex Hydro</td>
<td>LMJ</td>
</tr>
<tr>
<td>X-ray Thomson Scatt.*</td>
<td>Omega/NIF</td>
<td>Radiative shocks</td>
<td>LMJ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Magnetized Flows</td>
<td>LULI</td>
</tr>
</tbody>
</table>

*Posters by students/postdocs
# CLEAR Posters and Presentations

<table>
<thead>
<tr>
<th>Rad Hydro</th>
<th>Complex Hydro</th>
<th>Mag Hydro</th>
<th>Xray Diagnostics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray</td>
<td>Rasmus</td>
<td>Levesque</td>
<td>Belancourt</td>
</tr>
<tr>
<td>Vandercort</td>
<td>Ma</td>
<td>Young</td>
<td></td>
</tr>
<tr>
<td>Keiter</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Drake, Wednesday 10 am
We have been fabricating targets for our experiments since 2004.

Components for photoionization front gas target

Some components are fabricated at General Atomics

Sallee Klein and students gas filling targets at LLE

Omega-EP Kelvin Helmholtz target, Wan, Malamud
At the National Ignition we study the affect of energy transport effects on the Rayleigh-Taylor instability.

This work is relevant to SN1993J a core-collapse, red supergiant.

“How high energy fluxes may affect Rayleigh-Taylor instability growth in young supernova remnants”, *Nature Communications*, in press.
We use to NIF drive a create a high- and low-energy flux in an RT unstable system.

PI: Hye-Sook Park, Channing Huntington, Carolyn Kuranz
Typical data show qualitative and quantitative differences between cases.

![Images showing data plots for low and high energy flux at different times.](image-url)
We must compare the RT growth of each case

\[ \tau = \int \gamma_{RT} dt \]

\[ \gamma_{RT} = \sqrt{A(t)g(t)k} \]

A(t) is the Atwood number, g(t) is the acceleration and k is the wave number of the initial perturbation
We modeled the experiment in CRASH, a radiation hydrodynamic code

- 1D, 2D or 3D
- Dynamic adaptive AMR
- Level set interfaces
- Self-consistent EOS and opacities
- Multigroup-**diffusion radiation transport**
- Electron physics and flux-limited **electron heat conduction**
- Laser package
  - 3D ray tracing for 2D or 3D runs

Experimental data and CRASH simulations are in good agreement.
We found that high energy fluxes reduce the RT growth

- Energy fluxes due to radiative losses and electron heat conduction are large in SN1993J and the NIF experiment
- These fluxes should be considered in astrophysical modeling
- This work is in press at Nature Communications
- We have facility time at NIF through the Discovery Science Program to further explore this system
We are also exploring magnetized bow shocks

- Supersonic plasma outflows interact with astrophysical bodies, forming bow shocks
- Around magnetized objects, magnetic pressure alters flow dynamics
- A magnetopause forms where

\[ P_{ram} = \rho v^2 = P_B = \frac{B_0^2}{2\mu_0} \]
This is relevant to the Earth’s magnetosphere, which has complex dynamics.

Image credit: SOHO (NASA / ESA)
Proton radiography and imaging
Thomson scattering diagnostics
probe the shock

1 ns, 450 J lasers (6)
Imaging Thomson scattering measured plasma properties across a shock front

Analysis by Joseph Levesque
Proton radiography also provides information about the shock
We generated synthetic proton images using imaging TS data and imposed field.

The field jump at the shock is primary cause of the dark band(s).

Analysis by Joseph Levesque
We believe we have reached a suitable $\beta_{\text{ram}}$ regime for early times.

This experiment can be performed on pulsed power devices (MAIZE).
The Center for Laser Experimental Astrophysics Research studies high-energy-density phenomena that are relevant to astrophysics.

- **We advance fundamental understanding of HED dynamics relevant to astrophysics**
  - Radiation hydrodynamics
  - Complex HED hydrodynamics
  - Magnetized flowing plasma
- **While advancing the required infrastructures**
  - Computer simulation
  - Target fabrication
  - X-ray diagnostics
- **The ultimate goal of these activities is to train junior scientists**

X-ray radiography of a RT experiment at the National Ignition Facility with high energy fluxes
High Energy Density Physics
Summer School, June 11 – 22, 2018

Fundamental Equations
Equations of State
Shocks and Rarefactions
Hydrodynamic Instabilities
Radiative Transfer
Radiation Hydrodynamics
Creating HED Conditions
Inertial Fusion
Experimental Astrophysics
Relativistic Systems
Magnetohydrodynamics

NNSA will provide student funding!
http://clasp-research.engin.umich.edu/workshops/hedss/index.html
Backup Slides
Using ITS and proton imaging may allow us to infer magnetic field properties at the shock

- Generate synthetic proton images based on imposed magnetic field using ITS data
- Distance of shock from wire: 1.2 mm
- Estimated Shock depth (into page): 0.8 mm
- Assume no magnetic field behind shock

Analysis by Joseph Levesque